ENGINEERING
ECONOMICS

ME 481 Senior Design I
Fall 2021

Presented by
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based on presentation developed by Dr. Zhuoyuan Song
As global competition increases, engineers are increasingly asked to analyze and monitor their processes and products, not only to ascertain their level of quality but their cost-effectiveness as well.

– It is imperative to know the scientific and engineering principles of design work and decision-making in a world where technology is constantly evolving.

Where to Build: Far or Near?

Site A: $250,000
6 miles @ $15/mile
250 shipment / month

Site B: $500,000
5 miles @ $15/mile

By MIT OCW
## Where to Build: Far or Near?

<table>
<thead>
<tr>
<th>Cost</th>
<th>Site A</th>
<th>Site B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost to build @ site</td>
<td>$250,000</td>
<td>$500,000</td>
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<tr>
<td><strong>Monthly Costs</strong></td>
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<tr>
<td>Average Hauling Distance</td>
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<td>5 miles</td>
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<tr>
<td>Hauling Expense</td>
<td>$15</td>
<td>$15 /mile</td>
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<tr>
<td>Shipments</td>
<td>250</td>
<td>250 /month</td>
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<tr>
<td><strong>Total Monthly Cost</strong></td>
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<td>$18,750</td>
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<tr>
<td><strong>Monthly Savings</strong></td>
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<td>$3,750</td>
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By MIT OCW
Where to Build: Far or Near?

- **Simple payback:**
  - Site B is preferred after operating for just under 6 years
  - \( \frac{($500,000 - $250,000)}{3,750 \text{/ month}} \approx 67 \text{ months} \)

- **Considering reasonable business assumptions (15% discount rate)**
  - ???

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Site A:
- $250,000
- 250 shipment / month
- 6 miles @ $15/mile

Site B:
- $500,000
- 5 miles @ $15/mile

By MIT OCW
Where to Build: Far or Near?

- Considering reasonable business assumptions (15% discount rate)
  - $250,000 in cash with Site A, however…
  - $3,750 * 12 = $45,000 additional annual cost

  - Year 1: \[ FV = $250,000 \times 1.15 - $45,000 \] = $242,500
  - Year 2: \[ FV = $242,500 \times 1.15 - $45,000 \] = $233,875
  - Year 3: \[ FV = $233,875 \times 1.15 - $45,000 \] = $223,956
  - Year 4: \[ FV = $223,956 \times 1.15 - $45,000 \] = $212,550
  - Year 5: \[ FV = $212,550 \times 1.15 - $45,000 \] = $199,433
  - Year 6: \[ FV = $199,433 \times 1.15 - $45,000 \] = $184,348
  - Year 7: \[ FV = $184,348 \times 1.15 - $45,000 \] = $167,000
  - Year 8: \[ FV = $167,000 \times 1.15 - $45,000 \] = $147,050
  - Year 9: \[ FV = $147,050 \times 1.15 - $45,000 \] = $124,108
  - Year 10: \[ FV = $124,108 \times 1.15 - $45,000 \] = $ 97,724
  - Year 11: \[ FV = $ 97,724 \times 1.15 - $45,000 \] = $ 67,383
  - Year 12: \[ FV = $ 67,383 \times 1.15 - $45,000 \] = $ 32,490
  - Year 13: \[ FV = $ 32,490 \times 1.15 - $45,000 \] = $ - 7,637

- Site B is preferred after > 12 years!
Engineers seek solutions to problems, and the economic viability of each potential solution is normally considered along with the technical aspects.

"Economics is the study of how people and society choose to employ scarce resources that could have alternative uses in order to produce various commodities and to distribute them for consumption, now or in the future, ...”


Engineering economics is the application of economic principles to engineering problems.

Systematic evaluation of the economic merits of proposed solutions to engineering problems.

If factors can be valued in $$$, they should be included in the economic analysis
Why Engineering Economics?


Hewlett-Packard's ill-fated TouchPad.
What Do We Need to Know?

- Time value of money
- Estimation of cash flows
- Quantitative measurements of profitability
Time Value of Money

- Time value of money (TVM) is central to most engineering economic analyses. It’s the fundamentals underlying all financial activities!

- TVM: money that is available at the present time is worth more than the same amount in the future, given that the dollar today has the capacity to earn interest.

- In simpler terms:
  - A dollar was worth more yesterday than today;
  - A dollar today is worth more than a dollar tomorrow.
Cash Flow

- **Cash flow** is the net amount of *cash* and *cash*-equivalents being transferred into and out of a project.

Cash Flow Diagram (CFD)

- **Cash flow diagram** is adopted to show the cash flows for a project over time

![Cash Flow Diagram]

- **How to project cash flows?**
  - Cost estimation (the task of engineers!)
  - Product pricing and sales projection (Mutual efforts of S&M dept., consulting, engineers, and project managers)
Type of Costs

Two types of costs associated with an engineering project:

- **One-time costs**: first costs and salvage costs
- **Annual costs** (or benefits): occur every year or several years of the project

**First costs** or initial costs are the costs necessary to a project:

- Costs of new equipment
- Costs of shipping and installation
- Costs of renovations needed to install equipment
- Cost of engineering
- Cost of permits, licenses, etc.

**Annual costs** or periodic operational and maintenance costs of a project:

- Cost of utilities
- Cost of maintenance
- Cost of marketing and advertisement
- Cost of servicing and customer support
- Cost of recycling, etc.

First Costs also known as **Non-Recurring Expenditures (NRE)**
Annual Costs also known as **Recurring Expenditures (RE)**
Concept of Equivalence

Example: Opportunity to Invest

• Invest $15,000
• $18,000 return after 4 years

**Alternative 1:**

- $15,000 now
- $18,000 future

**Alternative 2:**

- $15,000 now
- 5% compound annual return on money market

<table>
<thead>
<tr>
<th>Year</th>
<th>Principal</th>
<th>Interest</th>
<th>Cumulated Cash Flow</th>
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<td>1</td>
<td>$15,000</td>
<td>$750</td>
<td>$15,750</td>
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<td>4</td>
<td>$17,364.38</td>
<td>$868.22</td>
<td>$18,234</td>
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Characterize Time Value

- **Present value (PV)** - money in hand at the present time, initial investment for future.
- **Future value (FV)** - ending amount at a point in time in the future. It should be worth more than the present value, provided it is earning interest and growing over time.
- **The number of periods (N)** - timeline for investment (or debts). It is usually measured in years, but it could be any scale of time such as quarterly, monthly, or even daily.
- **Interest rate (I)** - growth rate of your money over the lifetime of the investment. It is stated in a percentage value, such as 8% or 0.08.
- **Payment amount (PMT)** - These are a series of equal, evenly-spaced cash flows.
  - A – Uniform amount per interest period
  - G – Uniform gradient amount per interest period
Characterize Time Value

- Principal $P$
- Interest $i$ (% / year)
- $n$ year
- What is the future value $F$?

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

Factor notation:

\[
F = P \ (F/P, i, n)
\]

Interest factors

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<th>Year</th>
<th>Amount</th>
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<tr>
<td>0</td>
<td>$P$</td>
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<tr>
<td>1</td>
<td>$P(1 + i)$</td>
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<tr>
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<td>$P(1 + i)^3$</td>
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<tr>
<td>$n$</td>
<td>$P(1 + i)^n$</td>
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# Single Payment Formulas

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<th>Factor Name</th>
<th>Converts</th>
<th>Symbol</th>
<th>Formula</th>
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<td>Single Payment</td>
<td>to $F$ given $P$</td>
<td>$(F/P, i%, n)$</td>
<td>$(1 + i)^n$</td>
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<tr>
<td>Compound Amount</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Single Payment</td>
<td>to $P$ given $F$</td>
<td>$(P/F, i%, n)$</td>
<td>$(1 + i)^{-n}$</td>
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<tr>
<td>Present Worth</td>
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<td></td>
<td></td>
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<tr>
<td>Uniform Series</td>
<td>to $A$ given $F$</td>
<td>$(A/F, i%, n)$</td>
<td>$\frac{i}{(1+i)^n - 1}$</td>
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<td>Sinking Fund</td>
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<tr>
<td>Capital Recovery</td>
<td>to $A$ given $P$</td>
<td>$(A/P, i%, n)$</td>
<td>$\frac{i(1+i)^n}{(1+i)^n - 1}$</td>
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<tr>
<td>Uniform Series</td>
<td>to $F$ given $A$</td>
<td>$(F/A, i%, n)$</td>
<td>$\frac{(1+i)^n - 1}{i}$</td>
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<tr>
<td>Compound Amount</td>
<td>to $P$ given $A$</td>
<td>$(P/A, i%, n)$</td>
<td>$\frac{(1+i)^n - 1}{i(1+i)^n}$</td>
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<tr>
<td>Present Worth</td>
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<tr>
<td>Uniform Gradient</td>
<td>to $P$ given $G$</td>
<td>$(P/G, i%, n)$</td>
<td>$\frac{(1+i)^n - 1}{\frac{i^2(1+i)^n}{i(1+i)^n}} - \frac{n}{i}$</td>
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<tr>
<td>Present Worth</td>
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<tr>
<td>Uniform Gradient †</td>
<td>to $F$ given $G$</td>
<td>$(F/G, i%, n)$</td>
<td>$\frac{(1+i)^n - 1}{\frac{i^2}{i}} - \frac{n}{i}$</td>
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<tr>
<td>Future Worth</td>
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<tr>
<td>Uniform Gradient</td>
<td>to $A$ given $G$</td>
<td>$(A/G, i%, n)$</td>
<td>$\frac{1}{i} - \frac{n}{(1+i)^n - 1}$</td>
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<tr>
<td>Uniform Series</td>
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</tr>
</tbody>
</table>

†............. $F/G = (F/A - n)/i = (F/A) \times (A/G)$

A - Uniform amount per interest period

G - Uniform gradient amount per interest period

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Moves a single payment to $N$ periods later in time

Moves a single payment to $N$ periods earlier in time

Takes a single payment and spreads it into a uniform series over $N$ later periods.

Takes an arithmetic gradient series and moves it to a single payment two periods earlier than the first nonzero payment of the series.

NCEES Handbook

M. Nejhad, T. Sorensen  ME 481 – Fall 2021
# Factor Table

## Factor Table - \( i = 12.00\% \)

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<tr>
<th>( n )</th>
<th>( P/F )</th>
<th>( P/A )</th>
<th>( P/G )</th>
<th>( F/P )</th>
<th>( F/A )</th>
<th>( A/P )</th>
<th>( A/F )</th>
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<td><strong>8.3321</strong></td>
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Interest Rates

- **Compound interest rate**: interest is calculated on the initial principal and also includes all of the accumulated interest of previous periods of a principal.

- **Discount rate**: used in discounted cash flow analysis to determine the present value of future cash flows.
  - For example, to determine the present value of $1,000 a year from now, you need to discount it by a particular interest rate. Assuming a discount rate of 10%, the present value would be $909.09 = 1000/(1+0.1).

- **Hurdle rate**: the minimum rate of return on a project or investment required by a manager or investor.
  - The hurdle rate denotes appropriate compensation for the level of risk present; riskier projects generally have higher hurdle rates than those that are less risky.

- **Must meet the company’s investment criteria.**
  - Opportunity cost of the capital
Product Economics Example

- **Stanley Hammer**
- Designed in 1995 by Product Genesis for Stanley Tools
- Contractor Grade™
- Graphite composite shaft core with over-molded jacket
- Soft rubber grip

- Development cost and timing
- Testing cost and timing
- Tooling investment and timing
- Ramp-up cost and timing
- Marketing and support cost and timing
- Sales volume and lifetime
- Unit production cost
- Unit revenue
- Discount rate

$120k, 9 months
$100k, 1 year
$200k, 6 months
$50k, 3 months
$250k + $80k/year for 2 years
200k units/year, 5 years (actually not flat)
$4/unit + $2/unit overhead
$12/unit wholesale
10%/year

630k, 30 month
Quantification of Profitability

- **Profitability**: the central target of most projects!
- **Net Present Value (NPV)**

$$NPV = \sum_{\text{periods}} \frac{\text{period cash flow}}{(1 + \text{discount rate})^{\text{period}}}$$

$$NPV = \sum_{n=1}^{N} \frac{C_n}{(1+i)^n}$$

**Step 1**: Examines the total value of all cash flows at time 0.

**Step 2**: “i” as the rate of return that could be achieved otherwise, or cost of capital.

**Step 3**: If $NPV > 0$, the project is acceptable.

For our sample Cash Flow Diagram

- The expected rate of return (cost of capital): 10%
- The present value of C(0): $PV[C(0)] = -$10M
- The present value of C(3): $PV[C(3)] = 7/(1+10\%)^3 = $5.26M
- The net present value of the project: $SUM\{PV[C(i)]\} = $6.74M > 0
- Project accepted!

**Return on Investment**

$$RoI = \frac{\text{Annual Average Profit}}{\text{Total Investment}}$$

$$RoI = (7+7+15-10-5)/4/(10+5) = \sim 24\%$$

A Typical CFD for an engineering project
Summary

- Time value of money
  - Why does money have time value?
  - How to calculate?
- Cash flow and equivalence
- Interest factors
- Quantification of Profitability

- Take-aways:
  - $1 today ≠ $1 tomorrow
  - If factors can be valued in $$$, they should be included in the economic analysis

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