LESSON 21
ENERGY MANAGEMENT
ECONOMIC ANALYSIS
EXAMPLES

Southern Illinois University Department of Technology
QEM 570
Dr. Carl J. Spezia
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Learning Objectives

After this presentation you will be able to:

➢ Compare the results of various methods of economic analysis
➢ Setup economic analysis problems for energy savings opportunities
➢ Compute economic analysis using cost/benefit and ROR methods.
Methods of Economic Analysis

Present worth
Future worth
Annual worth

Benefit-Cost Ratio

Internal rate of return

Perform calculations and Compare methods of analysis

EXAMPLE PROBLEM

An Industrial plant operates a 100 hp three phase induction motor 7300 hours per year. The motor operates at a load factor of 0.75. This motor has an efficiency of 87% at this level. The motor recently failed and plant managers have two choices: a.) rewind the current motor or b.) purchase a new high efficiency (High-e) motor at a cost premium. The High-e motor has an efficiency of 94.5% at 0.75 load factor. The motor life is 10 years and the plants MARR is 10%. What is the best choice economically if electricity costs 0.066 $/kWh. The salvage value of the High-e machine is $1200 and the rewound motor will be $1000. Purchase prices are High-e: $100,000 and rewind: $85,000.

Perform the calculations using all methods of economic analysis and interpret the results for each method.
NET PRESENT VALUE

Subtract the sum that occur at the same point in time for both choices, then return all values to time zero. A positive present worth indicates an attractive project.

Define problem variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_o$</td>
<td>100 hp</td>
<td>Motor rated output</td>
</tr>
<tr>
<td>$LF$</td>
<td>0.75</td>
<td>Load factor of the motor</td>
</tr>
<tr>
<td>$\eta_{hie}$</td>
<td>0.945</td>
<td>Efficiency of high efficiency motor</td>
</tr>
<tr>
<td>$\eta_{rw}$</td>
<td>0.87</td>
<td>Efficiency of rewound motor</td>
</tr>
</tbody>
</table>

Conversion factor: 1 hp = 0.746 kW

NET PRESENT VALUE

Compute the input power for the High-e motor

The efficiency formula

$$\eta := \frac{P_o}{P_i}$$

Efficiency in per unit value

Solve for $P_{ihe}$ and convert to kW

$$P_{ihe} := \frac{P_o \cdot LF \cdot \left( \frac{0.746kW}{1\text{ hp}} \right)}{\eta_{hie}}$$

$P_{ihe} = 59.206kW$

Where:

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_o$ = 100hp</td>
<td></td>
</tr>
<tr>
<td>$LF = 0.75$</td>
<td></td>
</tr>
<tr>
<td>$\eta_{hie} = 0.95$</td>
<td></td>
</tr>
</tbody>
</table>
NET PRESENT VALUE

Compute the input power for the rewound motor

\[
P_{irw} = \frac{P_o \cdot LF \cdot 0.746 \text{kW}}{1 \text{ hp}} \cdot \eta_{rw}
\]

\[
P_{irw} = 64.3 \text{kW}
\]

Where:

\[
P_o = 100 \text{hp}
\]

\[
LF = 0.75
\]

\[
\eta_{rw} = 0.87
\]

Compute the annual energy savings from the High-e motor

\[
h := 7300 \text{hr} \quad \text{Operating hours per year}
\]

\[
E := h \cdot (P_{ih} - P_{irw})
\]

Energy reduction due to High-e motor

\[
E = -37,262 \text{kWh}
\]

NET PRESENT VALUE

Compute the net cost savings for High-e motor

The electric rate is:

\[
r_e := \frac{0.066 \text{ dollars}}{\text{kWh}}
\]

Compute the cost:

\[
NEC := -r_e \cdot E
\]

\[
NEC = 2459.3 \text{dollars}
\]

Given the purchase prices of the motors compute the net purchase price

\[
\text{Price of rewound motor} \quad PP_{rw} := -85000 \text{dollars}
\]

\[
\text{Price of high-e motor} \quad PP_{he} := -100000 \text{dollars}
\]

\[
\text{Net value of owning motors} \quad PP_{net} := PP_{he} - PP_{rw} \quad PP_{net} = -15000 \text{dollars}
\]
**NET PRESENT VALUE**

Compute the net value of motor salvage

\[ S_{hc} := 1200 \text{ dollars} \]
\[ S_{rw} := 1000 \text{ dollars} \]

Salvage value of the high-e motor
Salvage value of the rewound motor

\[ NS := S_{hc} - S_{rw} \]
\[ NS = 200 \text{ dollars} \]

Net salvage

Construct a cash flow diagram of the problem

\[ PP_{net} \]
\[ NEC \]
\[ NEC \]
\[ NEC \]
\[ NEC \]
\[ NEC \]
\[ NEC \]
\[ NEC \]
\[ NEC \]
\[ NEC \]
\[ NEC \]
\[ NEC \]
\[ NEC \]

\[ -15,000 \]

\[ 0 \]
\[ 1 \]
\[ 2 \]
\[ 3 \]
\[ 4 \]
\[ 9 \]
\[ 10 \]

**NET PRESENT VALUE**

Return all NEC’s and NS to t=0 using the formulas

Present value of future sum

\[ PV(n, i, FS) := FS \cdot \frac{1}{(1 + i)^n} \]

Present value of a series of end-of-period amounts

\[ PVS(n, i, A) := A \cdot \frac{(1 + i)^n - 1}{i(1 + i)^n} \]

\[ PP_{net} = -15000 \text{ dollars} \quad n = 10 \quad i = 0.1 \]

\[ PVS(n, i, NEC) = 15111 \text{ dollars} \quad PV(n, i, NS) = 77.11 \]

\[ PW := PP_{net} + PVS(n, i, NEC) + PV(n, i, NS) \]

\[ PW = 188.45 \text{ dollars} \]

Positive net present worth indicates that project is economical
**NET FUTURE VALUE**

Now do the same problem using the future worth method

Future value of a series of end-of-period amounts

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

Future value of a present sum

\[
FV(n, i, PS) := PS(1 + i)^n
\]

Remember the problem amounts

- \(PP_{net} = -15000\text{dollars}\)
- \(NFC = 2459.3\text{dollars}\)
- \(NS = 200\text{dollars}\)

**NET FUTURE VALUE**

Compute the future value by projecting the net purchase price and the annual energy savings to the end of the motors life.

\[
FW := FV(n, i, PP_{net}) + FVS(n, i, NEC) + NS
\]

\[
FW = 488.8\text{dollars}
\]

Positive future worth indicates that the High-e selection is economically attractive
ANNUAL WORTH METHOD

Distribute the net motor purchase price and the salvage over the lifetime of the machine.

\[
D(n, i, FV) := FV \frac{i}{(1 + i)^n - 1}
\]

Sinking-fund deposit function (end of period deposit, D required to amass a given future sum with interest)

The SFDF will divide the net salvage over the lifetime of the motor

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

Capital-recovery function (end of period payment, P required to recover a present amount with interest)

The CRF will divide the net purchase price over the life of the motor

ANNUAL WORTH METHOD

Compute the annual worth

\[
PP_{net} = -15000 \text{dollars} \quad NS = 200 \text{dollars} \quad NEC = 2459.3 \text{dollars}
\]

\[
P(n, i, PP_{net}) = -2441.18 \text{dollars} \quad D(n, i, NS) = 12.55 \text{dollars}
\]

\[
AW := NEC + P(n, i, PP_{net}) + D(n, i, NS)
\]

\[
AW = 30.67 \text{dollars} \quad \text{Answer}
\]

The computed annual worth value is positive so the choice of the High-e motor is economically justified given the problem assumptions.
**BENEFIT-COST RATIO**

To compute the benefit-cost ratio, move all sums and series values to time zero and divide the present worth of the benefits by the present worth of the costs.

Costs of motor project

\[ PP_{\text{net}} = -15000 \text{ dollars} \quad \text{Additional cost of high-e motor} \]

Benefits of motor project: Net energy savings and salvage

\[ PW_{\text{nec}} := PV(n, i, NEC) \quad \text{NEC} = 2459.3 \text{ dollars} \quad PW_{\text{nec}} = 15111.35 \text{ dollars} \]

\[ PW_{\text{NS}} := PV(n, i, NS) \quad \text{NS} = 200 \text{ dollars} \quad PW_{\text{NS}} = 77.11 \text{ dollars} \]

**BENEFIT-COST RATIO**

Benefit-cost ratio calculation

\[ BCR = \frac{\sum \text{Present worth benefits}}{\sum \text{Present worth costs}} \]

For this example

\[ BCR := \frac{PW_{\text{nec}} + PW_{\text{NS}}}{|PP_{\text{net}}|} \]

\[ BCR = 1.01 \quad \text{ Absolute value due to negative costs} \]

BCR > 1 so High-e motor is an economical project
INTERNAL RATE OF RETURN

To use this method, equate the costs and benefits of the project and solve for the interest rate \( i \) that satisfies the equation.

This is the most difficult method to find since all factor equations are complex equations of \( i \).

\[
PP_{net} = PVS(n, i, NEC) + PV(n, i, NS) \\
15,000 = PVS(10, i, 2459) + PV(10, i, 200) \\
15,000 = 2459 \left[ \frac{(1+i)^{10} - 1}{i(1+i)^{10}} \right] + 200 \left[ \frac{1}{(1+i)^{10}} \right] \\
\]

Solve for \( i \) using calculator, computer program or spreadsheet (IRR function)

\( i = 0.1029 \) or \( 10.29\% \)

Answer

INTERNAL RATE OF RETURN

Calculation interpretation

The project has an IRR of 10.29%. It just recovers the costs of the high-e motor through its higher efficiency.

This is an economical project based on the assumptions since:

\[
\text{computed } i > MARR \\
MARR = 0.1 \text{ (10\%)} \\
\]

Note: all methods give the same decision: High-e motor returns its additional cost over a period of 10 years if the MARR is 10%.

Other project may provide greater economic benefits and should be considered above this project.
END LESSON 21

ENERGY MANAGEMENT

ECONOMIC ANALYSIS EXAMPLES