Chapter 13. Replacement analysis

Up to now, we have considered the evaluation and selection of *new* alternatives: e.g., whether to buy or install new production machine. More frequently, economic analysis weighs *existing* versus *new* facilities. That is, whether we continue to use the existing equipment or replace it with new equipment. This chapter considers the replacement analysis in decision making.

CASE: AIRCRAFT REPLACEMENT

- American Airlines Inc. has a fleet of aging airplanes and a hard decision to make (Dallas Morning News, March 9, 2008).
  - Every day it flies aging McDonnell Douglas MD-80s.
  - It burns 20 % to 30 % more fuel than it would use with today's replacement airplane, the Boeing 737-800.
- Cost comparisons
  - An MD-80 burns 3,334 gallons of jet fuel on a trip from Dallas to NYC.
  - The Boeing 737-800 burns 2,455 gallons for the same trip, a saving of $2,285 with jet fuel at $2.60 a gallon.
- Despite aggressive efforts, American's annual spending on jet fuel jumped from $2.55 billion in 2002 to $6.67 billion in 2007.
- The airline is contemplating the replacement of its old airplanes. The decision is when (now or later)!

1. Replacement problem

- Capital assets age over time, and aging equipment has a greater risk of breakdowns.
  - Planned replacements help minimize the cost of disruption.
  - Managers should periodically evaluate the inventory of capital assets and make a decision on them.
  - In each year, firms should decide whether to keep the current equipment (defender) or replace it with a new one (challenger).
- Issues of replacement decision
  - Replacement decision considers only the *costs* of the defender and challenger.
  - If the challenger has better features and performance (i.e., benefits), these can be included as a *cost saving*.
  - The decision is based on the per-year cost, using the *equivalent uniform annual cost* (*EUAC*).

2. Costs of challenger and defender

- We use different concepts of cost for challenger and defender.
  - For **challenger**, we calculate the *minimum cost life* and *equivalent uniform annual cost* (EUAC).
  - For **defender**, we calculate the *marginal cost* for keeping the existing asset for one more year.
  - We then compare these costs to find the lowest one in order to make a replacement decision.
- Types of costs in assets
  - *Capacity cost* (or fixed cost): Capital cost and installation cost
    - It occurs regardless of the actual production.
    - This cost can be spread out through the life of an asset.
  - *Operating cost* (or variable cost): Electricity, gasoline, etc.
    - This cost is incurred every period (usually, every year).
    - This cost tends to increase as the asset gets old.

2.1. Challenger: EUAC

- Minimum cost life
  - The number of years at which the EUAC of ownership is minimized.
  - It is often shorter than the asset's useful life, due to increasing operating and maintenance costs in later years.
  - For challenger, we calculate the EUAC for each possible life of use.
- How to calculate equivalent uniform annual cost (EUAC)?
  - EUAC (total) = EUAC (capital) + EUAC (operation)
  - EUAC (capital) decreases as an asset is used longer.
  - EUAC (operation) increases with asset life due to aging.
  - Thus, EUAC (total) often has a *U-shaped* cost curve, and we can find the minimum cost life and its corresponding EUAC.
  - For an *old machine*, EUAC may continuously be increasing because EUAC (operation) is likely to dominate EUAC (capital).

EXAMPLE 2-1. MINIMUM COST LIFE (1)

- A piece of machinery costs $7,500 and has no salvage value.
  - The *maintenance costs* will be $900 in the second year, increasing by $900 every year afterwards.
  - The *operating expenses* will be $500 in the first year, increasing by $400 every year afterwards.
- If interest is 8%, what is the machinery's economic life that minimizes the EUAC?

  - For the new machine, we will calculate EUAC of capital and EUAC of M&O (maintenance & operation) for each possible life of use.
  - We then find the year at which the EUAC (total) is minimized.
  - Note that we are calculating the EUAC for each different service life, not for each year.

Example 2-1. Minimum cost life (2)

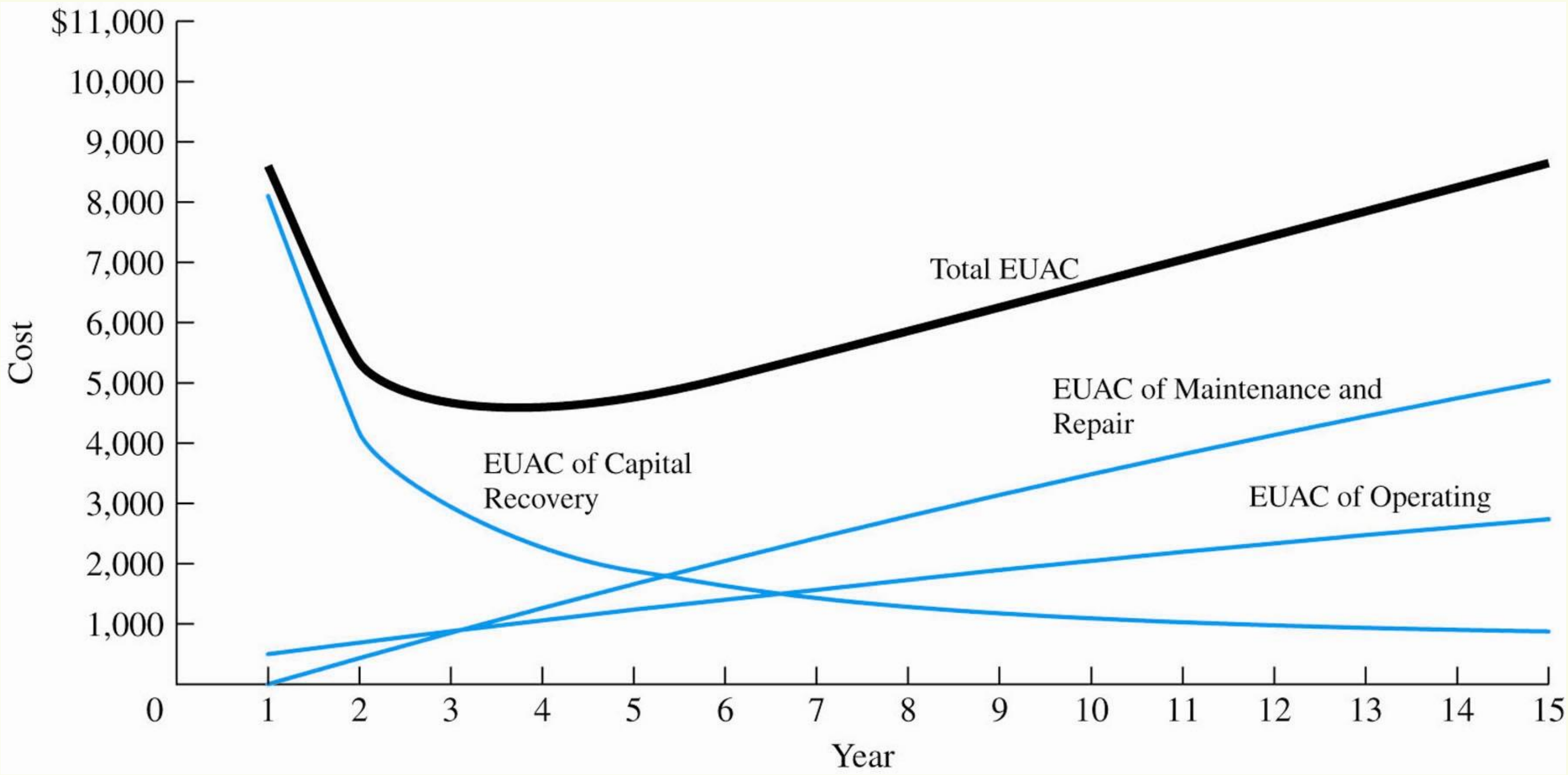
Year	Capital	M&O	EUAC (capital)	EUAC (M&O)	EUAC (total)
0	7,500				
1		500	8,100	500	8,600
2		1,800	4,206	1,125	5,331
3		3,100	2,910	1,733	4,644
4		4,400	2,264	2,325	**4,590**
5		5,700	1,878	2,900	4,779
6		7,000	1,622	3,459	5,082
7		8,300	1,441	4,002	5,442

- EUAC (capital) = 7,500(A/P, 8%, n)
- EUAC (M&O, n = 2) = [500(P/F, 8%, 1) + 1,800(P/F, 8%, 2)](A/P, 8%, 2)

Or EUAC (M&O, n = 4) = 500 + 1,300(A/G, 8%, 4)

EXAMPLE 2-1. MINIMUM COST LIFE (3)

- EUAC (total) tends to follow the *U-curve* shape.
  - It is high at the beginning due to high capital cost.
  - It is high at the end due to increased maintenance/operating costs.



Example 2-2. Minimum cost life (1)

- Jiffy Co. plans to install a molding system.
  - The molder costs $20,000 and the installation cost is $5,000.
  - Operating costs are $30,000 in the first year and increase by 5% every year.
  - The salvage value follows a declining-balance model with a 40% depreciation rate.
  - Assume there will be on-going need for the molder and the technology does not change.
- If the MARR is 15%, what is the economic life that minimizes the EUAC of the molder?

Example 2-2. Minimum cost life (2)

Year	Capital	Operation	EUAC (capital)	EUAC (op.)	EUAC (total)
0	20,000				
1	12,000	30,000	16,750	30,000	46,750
2	7,200	31,500	12,029	30,698	42,727
3	4,320	33,075	9,705	31,383	41,088
4	2,592	34,729	8,238	32,053	40,291
5	1,555	36,465	7,227	32,707	39,935
6	933	38,288	6,499	33,345	**39,844**
7	560	40,203	5,958	33,964	39,923
8	336	42,213	5,547	34,565	40,112

2.2. Defender: Marginal cost

- For the defender (an old asset), we often calculate the marginal cost which is the year-by-year costs of keeping an asset.
  - We can also calculate EUAC for the defender, but it is likely to increase over the life.
  - The marginal cost is simply the cost of keeping *one more year*.
  - The marginal cost includes
    - Annual capital recovery cost (which requires an asset's market value),
    - Annual operating and maintenance costs, and
    - Other expenses that occur during that year.
- Replacement decision
  - If the defender's marginal cost is *increasing*, it is directly compared with the challenger's EUAC.
  - If it is *not increasing*, we need to calculate the defender's EUAC and compare it with the challenger's EUAC.

Example 2-3. Marginal cost calculation (1)

- A new piece of production machinery has the following costs.
  - Investment cost = $25,000
  - Annual operating and maintenance cost = $2,000 in year 1 and then increasing by $500 per year.
  - Annual cost for risk of breakdown = $5,000 per year for 3 years and then increasing by $1,500 per year.
  - Useful life = 7 years
  - MARR = 15%
  - Salvage value: $18,000 in year 1, then $13,000, $9,000, $6,000, $4,000, $3,000, and $2,500 in year 7.
- Calculate the *marginal cost* of keeping this asset over its life.
  - We will calculate the marginal costs of the asset for each year.

Example 2-3. Marginal cost calculation (2)

Year	Capital cost	Marginal capital cost	O&M cost	Cost of risk	Marginal cost
1	18,000	10,750	2,000	5,000	17,750
2	13,000	7,700	2,500	5,000	15,200
3	9,000	5,950	3,000	5,000	13,950
4	6,000	4,350	3,500	6,500	14,350
5	4,000	2,900	4,000	8,000	14,900
6	3,000	1,600	4,500	9,500	15,600
7	2,500	950	5,000	11,000	16,950

- Marginal capital cost (at n = 2) = 18,000(A/P, 15%, 1) – 13,000
- Each year's marginal cost is the addition of each cost element.

Example 2-4. Marginal cost

- An used asset has a market value of $15,000 today, and its value will decrease by $1,000 per year over the next 5 years. Operating expenses will be $10,000 this year, but will increase by $1,500 per year. If the MARR is 15%, calculate the total *marginal cost* of its ownership for each of the next 5 years.

Year	Capital cost	Marginal capital cost	O&M cost	Marginal cost
1	14,000	3,250	10,000	13,250
2	13,000	3,100	11,500	14,600
3	12,000	2,950	13,000	15,950
4	11,000	2,800	14,500	17,300
5	10,000	2,650	16,000	18,650

- Note that the marginal cost is increasing.

3. Replacement analysis techniques

- Depending on the shape (or information) of the marginal cost, one of the three techniques is used.
- Technique 1: Defender's marginal cost is increasing.
  - Compare defender's *marginal costs* with EUAC (challenger).
- Technique 2: Defender's marginal cost is not increasing.
  - Compare *EUAC (defender*), and compare it with EUAC (challenger).
- Technique 3: Defender's marginal cost cannot be computed.
  - Calculate *EUAC (defender*) over its stated life and compare it with EUAC (challenger).
- Replacement repeatability assumptions
  - Currently available best challenger will continue to be available in subsequent years and will be unchanged in its economic costs.
  - The period of needed services of the asset is indefinitely long.

Example 3-1. Increasing marginal cost (1)

- Assume the machinery in example 2-4 as the defender and the machinery in example 2-3 as the challenger. Determine when, if at all, a replacement decision should be made.
- Machinery in example 2-3 (challenger)
  - Investment cost = $25,000
  - Annual operating and maintenance cost = $2,000 in year 1 and then increasing by $500 per year.
  - Annual cost for risk of breakdown = $5,000 per year for 3 years and then increasing by $1,500 per year.
  - Useful life = 7 years
  - MARR = 15%
  - Salvage value: $18,000 in year 1, then $13,000, $9,000, $6,000, $4,000, $3,000, and $2,500 in year 7.

Example 3-1. Increasing marginal cost (2)

- Since the marginal cost of the defender in example 2-4 is increasing, and we will compare it with EUAC of the challenger.
- To calculate EUAC of the challenger, we can directly calculate it (similar to example 2-1), or use the marginal costs from example 2-3.

Year	Capital market value	O&M + risk	EUAC (capital)	EUAC (O&M+ risk)	EUAC (total)
1	18,000	7,000	10,750	7,000	17,750
2	13,000	7,500	9,331	7,233	16,564
3	9,000	8,000	8,358	7,454	15,811
4	6,000	10,000	7,555	7,964	15,519
5	4,000	12,000	6,865	8,562	**15,427**
6	3,000	14,000	6,263	9,183	15,447
7	2,500	16,000	5,783	9,799	15,582

Example 3-1. Increasing marginal cost (3)

- Or, we can convert the marginal costs of example 2-3 to EUAC.
- We convert the marginal costs to the *present worth* by multiplying (P/F) factor, and then *annualize it* by multiplying (A/P) factor.

Year	Marginal cost	Present cost (PC_n)	EUAC (total)
1	17,750	$PC_1 = 17{,}750(P/F, 15\%, 1)$	$\times (A/P, 15\%, 1) = 17{,}750$
2	15,200	$PC_2 = PC_1 + 15{,}200(P/F, 15\%, 2)$	$\times (A/P, 15\%, 2) = 16{,}564$
3	13,950	$PC_3 = PC_2 + 13{,}950(P/F, 15\%, 3)$	$\times (A/P, 15\%, 3) = 15{,}811$
4	14,350	$PC_4 = PC_3 + 14{,}350(P/F, 15\%, 4)$	$\times (A/P, 15\%, 4) = 15{,}519$
5	14,900	$PC_5 = PC_4 + 14{,}900(P/F, 15\%, 5)$	$\times (A/P, 15\%, 5) =$ **15,427**
6	15,600	$PC_6 = PC_5 + 15{,}600(P/F, 15\%, 6)$	$\times (A/P, 15\%, 6) = 15{,}447$
7	16,950	$PC_7 = PC_6 + 16{,}950(P/F, 15\%, 7)$	$\times (A/P, 15\%, 7) = 15{,}582$

Example 3-1. Increasing marginal cost (4)

- For the challenger, a minimum EUAC of $15,427 is attained at year 5.
- That is, if the challenger is replaced every 5 years, its annual cost is $15,427.
- We compare EUAC (challenger) with the marginal cost (defender).

Year	Marginal cost (Defender)	Minimum EUAC (Challenger)	Recommendation
1	$13,250	$15,427	Keep defender
2	$14,600	$15,427	Keep defender
3	**$15,950**	**$15,427**	**Replace defender**
4	$17,300	$15,427	

- We should keep the defender for 2 more years and then replace it with the challenger in year 3.

Example 3-2. Increasing marginal cost (1)

- Five years ago, Martin installed production machinery with a cost of $25,000.
  - The annual operating costs were estimated at $1,250, increasing by $500 each year.
  - The market value of this machinery each year would be 90% of the previous year's value.
- Now, a new machine is available with a cost of $27,900.
  - There is no annual operating cost for this new machine over its *5-year minimum cost life*.
  - The salvage value of the machine is zero after 5 years.
- If the interest rate is 8%, when, if at all, should he replace the existing machine with the new one?

Example 3-2. Increasing marginal cost (2)

Year	Time	Capital market value	Marginal capital cost	Annual cost	Marginal cost
0	–5	25,000			
1	–4	22,500	4,500	1,250	5,750
2	–3	20,250	4,050	1,750	5,800
3	–2	18,225	3,645	2,250	5,895
4	–1	16,403	3,281	2,750	6,031
5	0	14,762	2,952	3,250	6,202
6	1	13,286	2,657	3,750	6,407
7	2	11,957	2,391	4,250	6,641
8	3	10,762	2,152	4,750	6,902
9	4	9,686	1,937	5,250	7,187
10	5	8,717	1,743	5,750	7,493

Example 3-2. Increasing marginal cost (3)

- As of now (year 5 in the previous table), the marginal cost of the defender is strictly increasing.
- We can easily calculate the challenger's EUAC with n = 5.

  EUAC = 27,900(A/P, 8%, 5) = $6,989

Year	Marginal cost (Defender)	Minimum EUAC (Challenger)	Recommendation
1	$6,407	$6,989	Keep defender
2	$6,641	$6,989	Keep defender
3	$6,902	$6,989	Keep defender
4	**$7,187**	**$6,989**	**Replace defender**
5	$7,493	$6,989	

- He should replace the machine with a challenger in year 4.

Example 3-3. Non-increasing marginal cost (1)

- Continuing example 3-1, suppose the defender's marginal cost is as follows. When, if at all, should the defender be replaced?

Year	Defender's marginal cost	Challenger's minimum EUAC
1	\$16,000	\$15,427
2	\$14,000	\$15,427
3	\$13,500	\$15,427
4	\$15,300	\$15,427
5	\$17,500	\$15,427

- The defender's marginal cost is not consistently increasing.
- If we use technique 1, the recommendation would be to replace the defender now because \$16,000 > \$15,427.
- This would be the wrong choice.

Example 3-3. Non-increasing marginal cost (2)

- If the marginal cost is non-increasing, we have to calculate the defender's minimum EUAC.

n	Marginal cost	Present worth	EUAC (total)
1	\$16,000	$PC_1 = 16{,}000(P/F, 15\%, 1)$	$\times\ (A/P, 15\%, 1) = 16{,}000$
2	\$14,000	$PC_2 = PC_1 + 14{,}000(P/F, 15\%, 2)$	$\times\ (A/P, 15\%, 2) = 15{,}070$
3	\$13,500	$PC_3 = PC_2 + 13{,}500(P/F, 15\%, 3)$	$\times\ (A/P, 15\%, 3) = \mathbf{14{,}618}$
4	\$15,300	$PC_4 = PC_3 + 15{,}300(P/F, 15\%, 4)$	$\times\ (A/P, 15\%, 4) = 14{,}754$
5	\$17,500	$PC_5 = PC_4 + 17{,}500(P/F, 15\%, 5)$	$\times\ (A/P, 15\%, 5) = 15{,}162$

- The minimum EUAC of the defender is \$14,618 when $n = 3$.
- We compare this value with the challenger's EUAC of \$15,427.
- Thus, we will keep the defender for at least 3 years.

4. After-tax replacement analysis

- An after-tax analysis provides greater realism and insight.
- After-tax effects may influence calculations in the defender-challenger comparisons.
- Marginal costs on an after-tax basis
  - We must consider the effects of ordinary taxes, gains and losses due to asset disposal.
- Minimum cost life problems
  - The after-tax minimum EUAC depends both on the depreciation method used and on changes in the asset's market value over time.
  - Considering an CCA tends to reduce the after-tax costs early in the asset's life.
  - This alters the shape of the total EUAC curve. The concave shape can be shifted and the minimum EUAC changes.

Example 4-1. After-tax marginal cost (1)

- A new production machinery has the following costs, example 2-3.
  - Investment cost = $25,000
  - Annual operating and maintenance cost = $2,000 in year 1 and then increasing by $500 per year.
  - Annual cost for risk of breakdown = $5,000 per year for 3 years and then increasing by $1,500 per year.
  - Useful life = 7 years
  - Salvage value: $18,000 in year 1, then $13,000, $9,000, $6,000, $4,000, $3,000, and $2,500 in year 7.
- In addition, we have the following information.
  - Depreciation is by the straight-line method with S = $0 and n = 5.
  - Tax rate is 40% and the after-tax MARR is 10%.
- Calculate the *after-tax marginal costs* of assets.

Example 4-1. After-tax marginal cost (2)

- We first calculate the after-tax market (or salvage) value of capital.
- Then, we consider depreciation tax savings for capital and after tax costs of operation and maintenance (next slide).

Year	Market value	Book value (SL depr.)	Recaptured CCA or loss	Tax (t = 40%)	After-tax market value
0	25,000	25,000			25,000
1	18,000	20,000	–2,000	–800	18,800
2	13,000	15,000	–2,000	–800	13,800
3	9,000	10,000	–1,000	–400	9,400
4	6,000	5,000	1,000	400	5,600
5	4,000	0	4,000	1,600	2,400
6	3,000	0	3,000	1,200	1,800
7	2,500	0	2,500	1,000	1,500

Example 4-1. After-tax marginal cost (3)

Year	After-tax market value	Marginal capital cost (with tax saving)	O&M cost × (1 – *t*)	Marginal cost
0	25,000			
1	18,800	6,700	4,200	10,900
2	13,800	4,880	4,500	9,380
3	9,400	3,780	4,800	**8,580**
4	5,600	2,740	6,000	8,740
5	2,400	1,760	7,200	8,960
6	1,800	840	8,400	9,240
7	1,500	480	9,600	10,080

- Marginal capital costs for year 1 – 5 include the tax savings of \$2,000 from capital depreciation (= \$5,000 × 40%).
- The after-tax marginal cost is much lower than the before-tax one.

SUMMARY OF CHAPTER 13

- Minimum cost life of a challenger and EUAC
- Marginal cost of defender
- Three techniques
  - Marginal cost increasing
  - Marginal cost non-increasing
  - Unknown marginal cost
- After-tax replacement

- Selective end of chapter problems
  - 9, 14, 19 (assume 10% interest rate), 32, 34, 38, 52, 55