In the name of Allah

Industrial Engineering Department

Course Title:
Engineering Economics

10. Replacement and Retention Decisions

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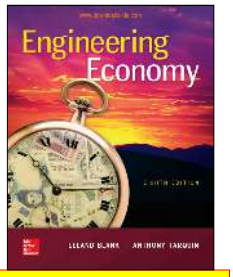
Learning Stage 3: Making Better Decisions

- Chapter 10 *not covered in this course
  - Project Financing and Noneconomic Attributes
- Chapter 11
  - Replacement and Retention Decisions
- Chapter 12 *not covered in this course
  - Independent Projects with Budget Limitation
- Chapter 13
  - Breakeven and Payback Analysis



Chapter 11 of EE (BT) book 8th edition

LEARNING OUTCOMES

- Purpose:
  - Perform a replacement/retention study between an in-place asset, process, or system and one that could replace it.

1. Explain replacement terminology and basics
2. Determine economic service life (ESL)
3. Perform replacement/retention study
4. Understand special situations in replacement
5. Perform replacement study over specified time
6. Calculate trade-in value of defender

Replacement Study Basics

- Reasons for replacement study
  - Reduced performance
    - Because of physical deterioration, ability to perform at an expected level of reliability (being available & performing correctly when needed) or productivity (performing at a given level of quality and quantity) isn't present.
  - Altered requirements
    - New requirements of accuracy, speed, or other specifications cannot be met by the existing equipment or system
  - Obsolescence
    - International competition and rapidly changing technology make currently used systems and assets perform acceptably but less productively than new equipment.
    - premature replacement studies may be needed.
      - studies performed before the estimated useful or economic life is reached.

Replacement Study Basics

- Some terminologies
  - Defender: Currently installed asset
  - Challenger: Potential replacement for defender
  - Market value (MV): Value of defender if sold in the open market
  - Economic service life (ESL): No. of years at which lowest AW of cost occurs
  - Defender first cost: MV of defender; used as its first cost (P) in analysis
  - Challenger first cost: Capital to recover for challenger (usually its P value)
    - The estimated initial investment necessary to acquire and install it.
  - Sunk cost: Prior expenditures that are not recoverable from challenger cost
  - Nonowner's viewpoint: Outsider's (consultant's) viewpoint for objectivity
    - This viewpoint performs the analysis without bias; i.e., the analyst owns neither the defender nor the challenger.

٥ Engineering Economics

Example: Replacement Basics

- An asset purchased 2 years ago for $40,000 is harder to maintain than expected.
  - The defender can be sold now for $12,000 or kept for a maximum of 2 more years, in which case its operating cost will be $20,000 each year, with a salvage value of $9,000 two years from now.
  - A suitable challenger will have a first cost of $60,000 with an annual operating cost of $4,100 per year and a salvage value of $15,000 after 5 years.
  - Determine the values of P, A, n, and S for the defender and the challenger for an AW analysis.

Solution:

Defender: $P = \$-12{,}000;\ A = \$-20{,}000;\ n = 2;\ S = \$9{,}000$

Challenger: $P = \$-60{,}000;\ A = \$-4{,}100;\ n = 5;\ S = \$15{,}000$

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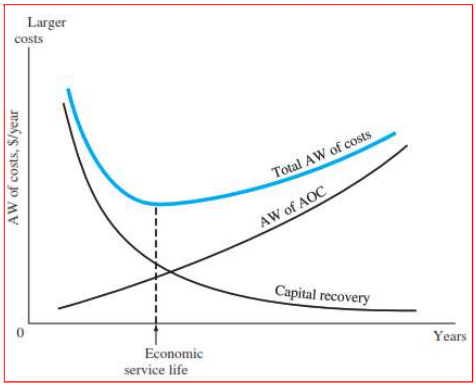
Overview of a Replacement Study

- Replacement studies are applications of the AW method
- Study periods (planning horizons) are either specified or unlimited
- Assumptions for unlimited study period:
  - Services provided for indefinite future
  - Challenger is best available now and for future, and will be repeated in future life cycles
  - Cost estimates for each life cycle for defender and challenger remain the same
- If study period is specified, the above assumptions do not hold
- Replacement study procedures differ for the two cases

Economic Service Life

- Economic service life (ESL)
  - refers to the asset retention time (n) that yields its lowest equivalent AW
- Determined by calculating AW for 1, 2, 3,…n years



- General equation is:
  - Total AW = capital recovery − AW of annual operating costs
  - = CR − AW of AOC

$$\text{Total AW}_k = -P(A/P,i,k) + S_k(A/F,i,k) - \left[\sum_{j=1}^{j=k} \text{AOC}_j(P/F,i,j)\right](A/P,i,k)$$

Example 11.2 of the book

- A 3-year-old vehicle is being considered for early replacement.
  - Three years ago, it is purchased $35,000.
  - Its current market value (MV) is $20,000.
  - Estimated future market values (MV) and annual operating costs (AOC) for the next 5 years are given below.

Year j (1)	MV_j, $ (2)	AOC_j, $ (3)
1	10,000	−5,000
2	8,000	−6,500
3	6,000	−8,000
4	2,000	−9,500
5	0	−12,500

  - What is the Economic Service Life of this defender if the interest rate is 10% per year?

Example 11.2 of the book

- Solution by hand

Year j (1)	MV_j, $ (2)	AOC_j, $ (3)	Capital Recovery, $ (4)	AW of AOC, $ (5)	Total AW_j, $ (6) = (4) + (5)
1	10,000	−5,000	−12,000	−5,000	−17,000
2	8,000	−6,500	−7,714	−5,714	−13,428
3	6,000	−8,000	−6,230	−6,405	−12,635
4	2,000	−9,500	−5,878	−7,072	−12,950
5	0	−12,500	−5,276	−7,961	−13,237

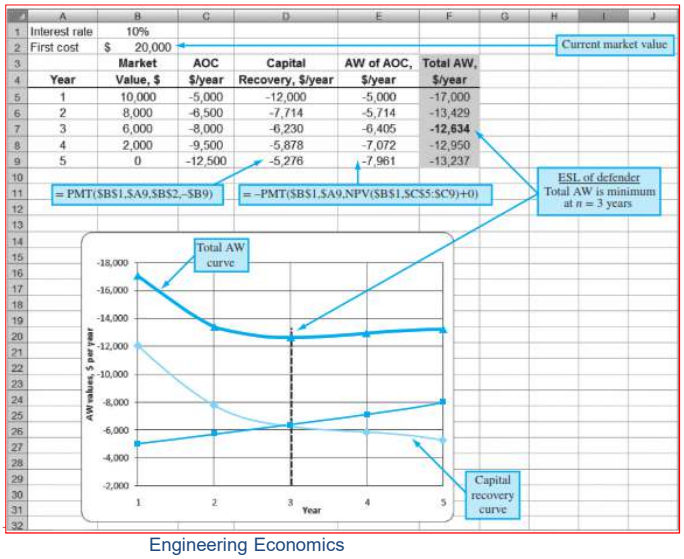
  - For example, for year 3

$$\begin{aligned}\text{Total AW}_3 &= -P(A/P,i,3) + \text{MV}_3(A/F,i,3) - [\text{PW of AOC}_1,\text{AOC}_2, \text{ and AOC}_3](A/P,i,3)\\ &= -20{,}000(A/P,10\%,3) + 6000(A/F,10\%,3) - [5000(P/F,10\%,1)\\ &\quad + 6500(P/F,10\%,2) + 8000(P/F,10\%,3)](A/P,10\%,3)\\ &= -6230 - 6405 = \$-12{,}635\end{aligned}$$

  - Therefore, ESL = 3 year with the lowest total AW.
  - In the replacement study, this AW will be
    - compared with the best challenger AW determined by a similar ESL analysis

Example 11.2 of the book

- Solution by spreadsheet.



Example: Economic Service Life

- Determine the ESL of an asset which has the costs shown below. Let i = 10%

Year	Cost,$/year	Salvage value,$
0	−20,000	n/a
1	−5,000	10,000
2	−6,500	8,000
3	−9,000	5,000
4	−11,000	5,000
5	−15,000	3,000

Solution:

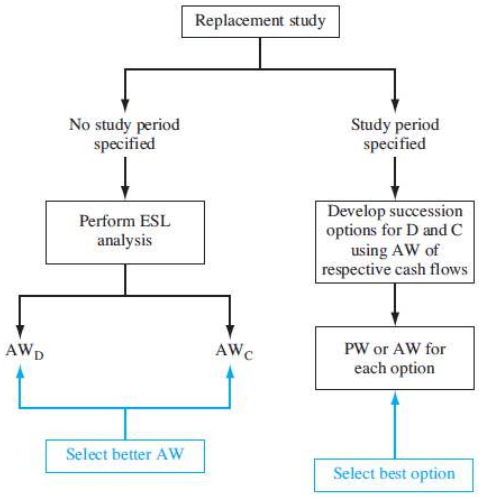
$AW_1 = -20{,}000(A/P, 10\%, 1) - 5000(P/F, 10\%, 1)(A/P, 10\% + 1) + 10{,}000(A/F, 10\%, 1) = \$ - 17{,}000$

$AW_2 = -20{,}000(A/P, 10\%, 2) - [5000(P/F, 10\%, 1) + 6500(P/F, 10\%, 2)](A/P, 10\%, 2) + 8000(A/F, 10\%, 2) = \$ - 13{,}429$

And similarly, $AW_3 = \$-13{,}239$, $AW_4 = \$ -12{,}864$, $AW_5 = \$ -13{,}62$

Therefore, Economic service life is 4 years

Performing a Replacement Study



Performing a Replacement Study – Unlimited Study Period

1. Calculate AW_D and AW_C based on their ESL; select lower AW
2. If AW_C was selected in step (1), keep for n_C years (i.e., economic service life of challenger)
   - if AW_D was selected, keep defender one more year and then repeat analysis (i.e., one-year-later analysis)
3. As long as all estimates remain current in succeeding years, keep defender until n_D is reached
   - and then replace defender with best challenger
4. If any estimates change before n_D is reached, repeat steps 1– 4

Note: If study period is specified, perform steps 1 – 4 only through end of study period (discussed later)

Example: Replacement Analysis

- An asset purchased 2 years ago for $40,000 is harder to maintain than expected.
  - The defender can be sold now for $12,000 or kept for a max of 2 more years, in which case its operating cost will be $20,000 each year, with a SV of $10,000 after 1 year or $9000 after 2 years.
  - A suitable challenger will have an annual worth of $-24,000 per year. At an interest rate of 10% per year, should the defender be replaced now, one year from now, or two years from now?

Solution: First, determine ESL for defender

$\mathbf{AW_{D1}} = -12{,}000(\mathrm{A/P}, 10\%, 1) - 20{,}000 + 10{,}000(\mathrm{A/F}, 10\%, 1) = \$-23{,}200$

$\mathbf{AW_{D2}} = -12{,}000(\mathrm{A/P}, 10\%, 2) - 20{,}000 + 9{,}000(\mathrm{A/F}, 10\%, 2) = \$-22{,}629$

ESL is n = 2 years; $AW_D = \$-22{,}629$; $AW_C = \$-24{,}000$; Lower AW = $\$-22{,}629$

Therefore, Replace defender in 2 years

Note: conduct one-year-later analysis next year.

Example 11.4 of the book

- Two years ago, Toshiba made a $15 million investment in new assembly line machinery.
  - It purchased approximately 200 units at $70,000 each and placed them in plants in 10 different countries.
    - This year, new international industry standards will require a $16,000 retrofit on each unit, in addition to the expected operating cost.
    - Due to the new standards, coupled with rapidly changing technology, a new system is challenging the retention of these 2-year-old machines.
  - A replacement study need to be performed this year and each year in the future, if need be. The i is 10% and the estimates are below.

Example 11.4 of the book

- Challenger:
  - First cost: $50,000
  - Future market values: decreasing by 20% per year
  - Estimated retention period: no more than 10 years
  - AOC estimates: $5000 in year 1 with increases of $2000 per year thereafter
- Defender:
  - Current international market value: $15,000
  - Future market values: decreasing by 20% per year
  - Estimated retention period: no more than 3 more years
  - AOC estimates: $4000 next year, increasing by $4000 per year thereafter, plus the $16,000 retrofit next year

Example 11.4 of the book

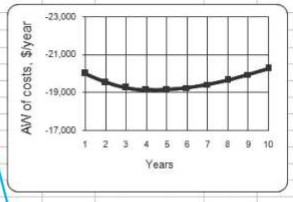
a. Determine the AW values and economic service lives necessary to perform the replacement study.
b. Perform the replacement study now.
c. After 1 year, the challenger is making large inroads to the market for electronic components assembly equipment, especially with the new international standards features built in.
   - The expected market value for the defender is still $12,000 this year, but it is expected to drop to $2000 next year on the worldwide market and zero after that.
   - Also, this prematurely outdated equipment is more costly to keep serviced, so the estimated AOC next year has been increased from $8000 to $12,000 and to $16,000 two years out.
   - Perform the follow-up replacement study analysis.

Example 11.4 of the book

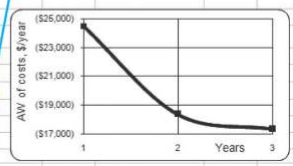
- Solution a)

$$\text{Total AW}_4 = -50{,}000(A/P,10\%,4) + 20{,}480(A/F,10\%,4) - [5000 + 2000(A/G,10\%,4)] = \$-19{,}123$$

	A	B	C	D	E	F
1	Interest rate	10%	ESL Analysis of Challenger			
2	First cost	$ 50,000				
3		Market				Total AW
4	Year	Value	AOC	Capital Recovery	AW of AOC	of costs
5	1	40,000	-5,000	-15,000	-5,000	-20,000
6	2	32,000	-7,000	-13,571	-5,952	-19,524
7	3	25,600	-9,000	-12,372	-6,873	-19,245
8	4	20,480	-11,000	-11,361	-7,762	-19,123
9	5	16,384	-13,000	-10,506	-8,620	-19,126
10	6	13,107	-15,000	-9,782	-9,447	-19,229
11	7	10,486	-17,000	-9,165	-10,243	-19,408
12	8	8,389	-19,000	-8,639	-11,009	-19,648
13	9	6,711	-21,000	-8,188	-11,745	-19,933
14	10	5,369	-23,000	-7,800	-12,451	-20,251
15	Formulas, year 10	'= B13*0.8	'= $C13-2000	'= PMT($B$1, $A14,$B$2,-$B14)	'= -PMT($B$1, $A14,NPV($B$1,$C$5:$C 14)+0)	'= E14+D14
16						
17	Interest rate	10%	ESL Analysis of Defender			
18	Market value	$ 15,000				
19		Market				Total AW
20	Year	Value	AOC	Capital Recovery	AW of AOC	of costs
21	1	12,000	-20,000	-4,500	-20,000	-24,500
22	2	9,600	-8,000	-4,071	-14,286	-18,357
23	3	7,680	-12,000	-3,711	-13,595	-17,307
24						
25						



ESL results



Example 11.4 of the book

- Solution b)
  - Challenger: $AW_C = \$-19{,}123$ for $n_C = 4$ years
  - Defender: $AW_D = \$-17{,}307$ for $n_D = 3$ years
    - Therefore, select the defender, and expect to retain it for 3 more years.
- Solution c) one-year-later analysis
  - For the defender, there is a maximum of 2 more years of retention

Year *k*	Market Value, $	AOC, $	Total AW If Retained *k* More Years, $
0	12,000	—	—
1	2,000	−12,000	−23,200
2	0	−16,000	−20,819

  - Challenger: unchanged at $AW_C = \$-19{,}123$ for $n_C = 4$ years
  - Defender: new $AW_D = \$-20{,}819$ for $n_D = 2$ more years
    - Keep the challenger for 4 years, or until a better challenger appears.

Additional Considerations

- Opportunity cost approach
  - The procedure that was previously presented for obtaining P for the defender.
  - The opportunity cost is
    - the money foregone by keeping the defender (i.e., not selling it).
  - This approach is always correct.
- Cash flow approach
  - Subtracts income received from sale of defender from first cost of challenger (e.g., net cost out of exchange of D & C).
  - Potential problems with cash flow approach:
    - Provides falsely low value for capital recovery of challenger
    - Can't be used if remaining life of defender is not same as that of challenger
- Use the initial investment of C and the market value of D as the first costs in the ESL analysis and in the replacement study.

Replacement Analysis:Specified Study Period

- Same procedure as before,
  - except calculate AW values over study period instead of over ESL years of n_D and n_C
- When D's remaining life is shorter than the study period,
  - cost of providing D's services from the end of its expected remaining life to the end of the study period must be estimated as accurately as possible and included in the replacement study.

1) It is necessary to develop all viable defender-challenger combinations and
   - calculate AW or PW for each one over the study period
2) Select option with the lowest cost or the highest income

Example: Replacement Analysis; Specified Period

- An asset purchased 2 years ago for $40,000 is harder to maintain than expected.
  - It can be sold now for $12,000 or kept for a maximum of 2 more years, in which case its operating cost will be $20,000 each year, with a salvage value of $10,000 after 1 year or $9000 after two.
  - A suitable challenger will have an annual worth of $-24,000 per year.
  - At an interest rate of 10% per year and over a study period of exactly 2 years, determine when the defender should be replaced.

Solution: From previous analysis, AW_D for 1 and 2 years, and AW_C are:

$$\mathbf{AW_{D1}} = \$ - 23{,}200 \quad \mathbf{AW_{D2}} = \$ - 22{,}629 \quad \mathbf{AW_C} = \$ - 24{,}000$$

Option	Year 1, $	Year 2, $	Year 3, $	AW, $
1 (C, C, C)	−24,000	−24,000	−24,000	−24,000
2 (D, C, C)	−23,200	−24,000	−24,000	−23,708
3 (D, D, C)	−22,629	−22,629	−24,000	−23,042

Decision: Option 3; Keep D for 2 years, then replace

Example 11.7 of the book

- Three years ago, Chicago Airport purchased a new fire truck.
  - Because of flight increases, new fire-fighting capacity is needed once again. There are two options:
    - An additional new truck of the same capacity can be purchased
    - A double-capacity truck can replace the current fire truck.
  - Estimates are presented below.

	Presently Owned	New Purchase	Double Capacity
First cost P, $	−151,000 (3 years ago)	−175,000	−190,000
AOC, $	−1,500	−1,500	−2,500
Market value, $	70,000	—	—
Salvage value, $	10% of P	12% of P	10% of P
Life, years	12	12	12

  - Compare the options at 12% per year using
    a) a 12-year study period and
    b) a 9-year study period.

Example 11.7 of the book

- Solution a)
  - Define the following two options:

	Option 1		Option 2
	Presently Owned	Augmentation	Double Capacity
P, \$	−70,000	−175,000	−190,000
AOC, \$	−1,500	−1,500	−2,500
S, \$	15,100	21,000	19,000
n, years	9	12	12

  - For a full-life 12-year study period of two options

$$\begin{aligned}AW_1 &= (\text{AW of presently owned}) + (\text{AW of augmentation})\\ &= [-70{,}000(A/P,12\%,9) + 15{,}100(A/F,12\%,9) - 1500]\\ &\quad + [-175{,}000(A/P,12\%,12) + 21{,}000(A/F,12\%,12) - 1500]\\ &= -13{,}616 - 28{,}882\\ &= \$-42{,}498\end{aligned}$$

$$\begin{aligned}AW_2 &= -190{,}000(A/P,12\%,12) + 19{,}000(A/F,12\%,12) - 2500\\ &= \$-32{,}386\end{aligned}$$

    - Therefore, replace now with the double-capacity truck (option 2) at an advantage of \$10,112 per year.

Example 11.7 of the book

- Solution b)
  - We need to calculate AWs during 9 years and
  - assuming SVs are the same since they are expressed as percentages of Ps for all years.
    - $AW_1 = \$-46{,}539$
    - $AW_2 = \$-36{,}873$
  - Therefore, Option 2 is again selected.

- When a study period shorter than the life of C is defined,
  - C's capital recovery amount increases in order to recover the initial investment plus a return in this shortened time period.
    - Highly shortened study periods tend to disadvantage the C because no consideration of time beyond the end of the study period is made in calculating C's capital recovery amount.

Example 11.8 of the book

- A replacement study has been done between a defender PT and a challenger GH as follows.
  - Challenger: AW_C=$−12.32 million with ESL n_C = 12 years.

	A	B	C	D	E	F
1	Interest rate	15%	ESL analysis		First cost, $	38.00
2		Market	AOC	Capital	AW of AOC,	Total AW,
3	Year	Value, $	$/year	Recovery, $/year	$/year	$/year
4	1	25.00	-3.40	-18.70	-3.40	-22.10
5	2	18.75	-3.74	-14.65	-3.56	-18.21
6	3	14.06	-4.11	-12.59	-3.72	-16.31
7	4	10.55	-4.53	-11.20	-3.88	-15.08
8	5	7.91	-4.98	-10.16	-4.04	-14.21
9	6	5.93	-7.48	-9.36	-4.43	-13.80
10	7	4.45	-6.02	-8.73	-4.58	-13.31
11	8	3.34	-6.63	-8.23	-4.73	-12.95
12	9	2.50	-7.29	-7.81	-4.88	-12.69
13	10	1.88	-8.02	-7.48	-5.03	-12.51
14	11	1.41	-8.82	-7.20	-5.19	-12.39
15	12	1.06	-9.70	-6.97	-5.35	-12.32
16	Formulas, year 12	'= B14*0.75	'= C14*1.1	'= PMT($B$1, $A15,$F$1,-$B15)	'= -PMT($B$1,$A15, NPV($B$1,$C$4:$C15)+0)	'= E15+D15

Example 11.8 of the book

- Defender: AW_D = $−8.50 million with n_D = 1 year

	A	B	C	D	E	F
1			ESL Analysis of PT			
2	Interest rate	15%			Market value	$ 22.00
3						
4		Market				Total AW
5	Year	Value	AOC	Capital Recovery	AW of AOC	of costs
6	1	22.00	-5.20	-3.30	-5.20	-8.50
7	2	22.00	-6.40	-3.30	-5.76	-9.06
8	3	22.00	-7.60	-3.30	-6.29	-9.59
9	4	20.00	-8.80	-3.70	-6.79	-10.49
10	5	18.00	-10.00	-3.89	-7.27	-11.16
11	6	18.00	-11.20	-3.76	-7.72	-11.47
12	Formula, year 3	22.00	-7.60	'= PMT($B$2, $A8,$F$2,-$B8)	'= -PMT($B$2,$A8, NPV($B$2,$C$6:$C8)+0)	'= D8+E8
13						

- D is the clear choice with a much smaller AW value than that of C.
- Considering the future situations,
  - when it is economically the cheapest to purchase C, provided the D is kept at least 1 year, but no more than 6 years, its remaining expected life?"

Example 11.8 of the book

- Solution
  - Study period is 6 years and
    - D will stay in place between 1 & 6 year.
    - C will be considered for 0 to 5 years of service.
  - So we have the following options.

Option	Defender PT		Challenger GH	
	Years Retained	AW, $ M/Year	Years Retained	AW, $ M/Year
A	1	−8.50	5	−14.21
B	2	−9.06	4	−15.08
C	3	−9.59	3	−16.31
D	4	−10.49	2	−18.21
E	5	−11.16	1	−22.10
F	6	−11.47	0	—

  - Now calculate AW or PW for each option.

Example 11.8 of the book

- Solution

	A	B	C	D	E	F	G	H	I	J
1		Time in Service, Years								Option
2		Defender	Challenger	AW Cash Flows for Each Option, $M per year						PW at 15%,
3	Option	PT	GH	1	2	3	4	5	6	$M
4	A	1	5	-8.50	-14.21	-14.21	-14.21	-14.21	-14.21	-48.81
5	B	2	4	-9.06	-9.06	-15.08	-15.08	-15.08	-15.08	-47.28
6	C	3	3	-9.59	-9.59	-9.59	-16.31	-16.31	-16.31	-46.38
7	D	4	2	-10.49	-10.49	-10.49	-10.49	-18.21	-18.21	-46.87
8	E	5	1	-11.16	-11.16	-11.16	-11.16	-11.16	-22.10	-46.96
9	F	6	0	-11.47	-11.47	-11.47	-11.47	-11.47	-11.47	**-43.41**
10										
11					Conclusion: Keep defender all 6 years					
12										
13										

  - So it is clearl to keep the defender in place for 6 more years.
- If the analysis is to be carried further,
  - Possibility of increased revenue/decreased AOC based on services of future C due to improved operating efficiency should be considered next.

Replacement Value

- Replacement value (RV):
  - market/trade-in value of defender that renders AW_D and AW_C equal to each other
- Set up equation $AW_D = AW_C$ except
  - use RV in place of P for the defender; then solve for RV
- If defender can be sold for amount > RV,
  - challenger is the better option, because it will have a lower AW value

Example: Replacement Value

- An asset purchased 2 years ago for $40,000 is harder to maintain than expected.
  - It can be sold now for $12,000 or kept for a maximum of 2 more years, in which case its operating cost will be $20,000 each year, with a salvage value of $10,000 at the end of year two.
  - A suitable challenger will have an initial cost of $65,000, an annual cost of $15,000, and a salvage value of $18,000 after its 5 year life.
  - Determine the RV of the defender that will render its AW equal to that of the challenger, using an interest rate of 10% per year.
  - Recommend a course of action.

Solution: Set $\mathbf{AW_D = AW_C}$

$$-\text{RV}(A/P, 10\%, 2) - 20{,}000 + 10{,}000(A/F, 10\%, 2) = -65{,}000(A/P, 10\%, 5) - 15{,}000 + 18{,}000(A/F, 10\%, 5)$$

$$\text{RV} = \$24{,}228$$

Thus, if market value of defender > $24,228, select challenger

Summary of Important Points

- In replacement study, P for presently-owned asset is its market value
- Economic service life is the n value that yields lowest AW
- In replacement study, if no study period is specified,
  - calculate AW over the respective life of each alternative
- Opportunity cost approach is correct,
  - it recognizes money foregone by keeping the defender, not by reducing challenger's first cost
- When study period is specified,
  - must consider all viable defender-challenger combinations in analysis
- Replacement value (RV) is
  - P value for defender that renders its AW equal to that of challenger