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Replacement Analysis for Air Compressors: a Case of a Petrochemical Company in Malaysia

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ABSTRACT

The study analyzes the economic justification of a proposal for replacement of three units of existing air compressors in a petrochemical company in Malaysia. Due to the huge capital investment, economic justification is primary in deciding the feasibility of this replacement problem, as it is commonly called. The engineering economy analysis model employed includes net present value, equivalent uniform annual cost, breakeven analysis and sensitivity analysis. Three factors namely capital investment, operating cost and labour cost were analyzed to determine their impact on the overall economics of the replacement proposal. The economic analysis showed that the compressors have to be replaced with a new unit immediately. The proposal is sensitive to the variation in the capital investment. However, it is impervious to the variation in the other two factors considered.

Key words: Replacement problem, net present value, equivalent uniform annual cost, breakeven analysis, sensitivity analysis, Malaysia

INTRODUCTION

The plants and machines used in production have to be managed to ensure reliable and efficient operations in generating sustainable return to investors. Businesses incur heavy losses when their equipment is not in full operation, hence, the need for availability and reliability of assets. The management challenge is made more complex in the light of competitive global market. Reliable and efficient operations of these technologies entail systematic asset maintenance management. These include among others, routine servicing and maintenance, periodic inspection and calibration, as well as replacement when necessary.

At some stage in the life cycle of the plants or machines, management encounters situation in deciding whether these plants or machines should be continued in service or replaced with new ones. Some of the reasons for the replacement problem, as it is commonly called, include physical impairment of the assets that leads to low reliability and productivity, altered requirements which cannot be met by the present assets and changes in technology that has favorable impact on quality or costs of production (Sullivan *et al*., 2012; Blank and Tarquin, 2008). Due to the huge capital investment of these assets, careful economic analyses have to be done to provide the information needed in making accurate replacement decisions. The failure in making appropriate replacement decisions have significant negative impact to the bottom-line of the businesses. Retaining the assets beyond their economic life may result in low reliability and inefficient operations. On the contrary, untimely assets replacement may drain a company's resources.

This study highlights a quantitative analysis of a replacement problem of air compressors at a Petrochemical Company in Malaysia. Compressed air is one of the utilities in petrochemical production processes apart from electricity, natural gas and water. With the large amount of compressed air consumption daily for various operations the economics and reliability of the supply is of utmost important (Sweeney, 2002). As the replacement proposal involves huge investment of capital, it is the objective of this study to ascertain the economic feasibility of the replacement using engineering economy analysis. The analyses involve various economic models such as equivalent uniform annual costs, net present value, breakeven analysis and sensitivity analysis.

PROBLEM STATEMENT

At the plant of a large petrochemical company in Malaysia, five units of air compressors are used to supply compressed air to nitrogen generation plant, instrument air header and service air header. Three units of the air compressors namely 84-K001, 84-K002 and 84-K003 with a combined power requirement of 796 kW were installed in 1985. These units are capable of supplying 994 $Nm^3 h^{-1}$ of compressed air each. The other two compressors; 84-K005 and 84-K006, which were installed in 1997 has a capacity of 2000 $Nm^3 h^{-1}$ each.

Due to continuous usage for more than 27 years, the condition of the 84-K001, 84-K002 and 84-K003 air compressors are deteriorating and significantly affect the reliability. This is reflected by the increase in the frequency of corrective and reactive maintenance of the air compressors as shown in Fig. 1.

Evidently the frequency of breakdowns of the 84-K001, 84-K002 and 84-K003 air compressors shows an upward trend, with an exception for the year 2005 as the plant was undergoing major revamp for a period of six months. Consequently the operation and maintenance costs have increased. The cost of compressed air production is one of the most expensive processes in the utility supply (Risi, 1995). Due to the costs and reliability issues, the company planned to replace the three air compressors with one new unit. Accordingly, two replacement alternatives were put forth. The first replacement alternative is 396 kW water-cooled centrifugal air compressor. The second alternative is 411 kW rotary screw air compressor.

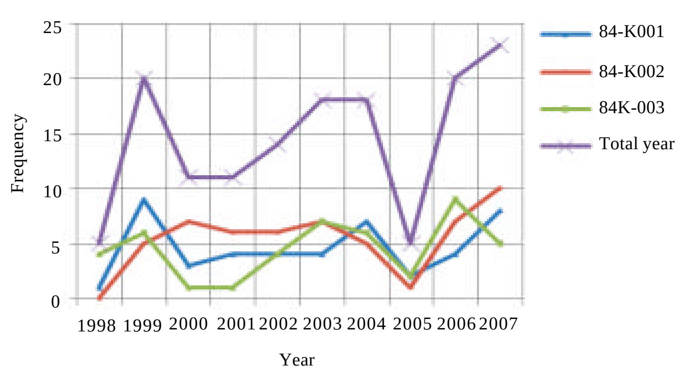

Fig. 1: Frequency of corrective and reactive maintenance

The economic analysis facilitates the managers of the company to decide on the following:

- When is the most appropriate time to replace the existing 84-K001, 84-K002 and 84-K003 air compressors
- Which new air compressor is the most economically preferable to replace the 84-K001, 84-K002 and 84-K003 air compressors

FORMULATION OF ECONOMIC MODEL

Various analytical models are used in the analysis of the economic feasibility of this replacement problem (Park, 2004). They are outlined below. For the purpose of the analysis, the existing air compressors are descriptively called the defender and the new air compressors are identified as the challengers. They are mutually exclusive alternatives.

Net present worth (PW): Discount future amounts to the present by using the interest rate over the appropriate study period:

$$PW = \sum_{k=0}^{N} F_k (1+i)^{-k} \quad (1)$$

where, i is MARR per compounding period, k is index for each compounding period, F_k is future cash flow at the end of period k and N is number of compounding periods in study period. If PW>0, it is economically justified.

Equivalent uniform annual costs (EUAC):

$$EUAC_k = [\sum_{j=1}^{k} TC_j (P/F, i\%, j)](A/P, i\%, k) \quad (2)$$

where, i is MARR per compounding period, j is index for each compounding period (j = 1, 2, 3,... n), k is index for each compounding period (k = 1, 2, 3,... n), TC_j is Total (marginal) cost for the year k and n is number of compounding periods in study period.

Breakeven analysis for mutually exclusive alternatives: This method is used to analyze the possible outcome of mutually exclusive alternatives. Generally, the values of the net Present Worth (PW), net Annual Worth (AW), or net Future Worth (FW) of each mutually exclusive alternative are plotted on the same graph over the range of each factor of concerned. The graph shows how the mutually exclusive alternatives changes as a function of the factor concerned. Based on this, the best alternative will become apparent:

$$Ew_a = f_1(y),\ Ewb = f_2(y), \text{---------},\ Ew_p = f_q(y) \quad (3)$$

where, EW is an equivalent worth (PW, AW, or FW) for the net cash flow of alternative a, b,... n, q is index for each compounding period (q = 1, 2, 3,... n), p is number of proposals or alternatives in the analysis (p = 1, 2, 3,... n), y is a common factor of interest affecting the equivalent worth (PW, AW, or FW).

Breakeven point between Alternative a and Alternative b is the value of y for which the two values of equivalent worth are equal. In other words, $EW_a = EW_b$ or $f_1(y) = f_2(y)$.

Sensitivity analysis: This method is used to examine the effect on the most-likely values of PW, FW, or AW of the proposal to the variations in the input variables namely revenues, costs, study duration, salvage value or the rate of return, to name a few. It is a non-probabilistic methodology to provide information pertaining to the impact of uncertainty of the input variables to the PW, FW, or AW. The relative magnitude of change in the PW, FW, or AW is investigated by varying the value of one input variable at a time, while the values of the other variables remain the same. Some of the variables have greater influence on the economic feasibility of the proposal than the others. With the sensitivity plot, the impact of the variation in the estimates of each variable on the PW, FW, or AW is visible. The slope of the plot show how sensitive the PW, FW, or AW is to changes in each variable.

FORMULATION OF SPREADSHEET MODEL

Net present worth (PW): The process of calculation PW is simplified using a spreadsheet as shown in Table 1 and detail calculation for the spreadsheet cell B11, C11, D11 and E11 are illustrated in Table 2.

Equivalent uniform annual costs (EUAC): Table 3 illustrates the use of spreadsheet to solve for the Equivalent Uniform Annual Costs (EUAC) of the proposals. The detail computation for the spreadsheet column C, column E, column F and column G are illustrated in Table 4.

Sensitivity analysis: Table 5 shows the spreadsheet formulation for PW estimates for varied factor values in the range of ±40% from the most-likely estimates. Each cell B9, C9, D9 and E9 has distinctive formulae that refer to the factors F1, F2, F3 and F4 in computing the PW values as indicated in Table 6. The PW estimates of the remaining cells are computed by copying down the columns accordingly. Based on the computed value of PW, sensitivity plots are constructed.

Table 1: A spreadsheet model to calculate equivalent present worth

	A	B	C	D	E
1	MARR	i%			
2	Useful life	k			
3					
4	EOY	Alt 1	Alt 2	-	Alt n
5	0	C_{10}	C_{20}	-	C_{n0}
6	1	C_{11}	C_{21}	-	C_{n1}
7	2	C_{12}	C_{22}		C_{n2}
8					
9					
10	k	C_{1k}	C_{2k}	-	C_{nk}
11	Present worth	PW_1	PW_2	-	PW_n

Table 2: Computation of equivalent present worth

B11	C11	D11	E11
=NPV($B$1,B6:B10)+B5	=NPV($B$1,C6:C10)+C5	=NPV($B$1,D6:D10)+D5	=NPV($B$1,E6:E10)+E5

Table 3: A spreadsheet model for equivalent uniform annual costs

	A	B	C	D	E	F	G
1	MARR	i%					
2							
3	End of year, k	End of year (EOY) Mv_k	Capital recovery amount (CR_k)	Annual expenses (E_k)	PW of annual expenses, Pw_k	Equivalent uniform annual cost of annual expenses, $EUAC_k$	Cumulative $\Sigma EUAC_k$
4	0	I	-	-	-	-	-
5	1	MV_1	CR_1	E_1	PW_1	$EUAC_1$	$\Sigma EUAC_1$
6	2	MV_2	CR_2	E_2	PW_2	$EUAC_2$	$\Sigma EUAC_1$
7							
8							
9	k-1	MV_{k-1}	CR_{k-1}				
10	k	MV_k	CR_k	E_k	PW_k	$EUAC_k$	$\Sigma EUAC_k$

Table 4: Computation of equivalent uniform annual costs (EUAC)

Spreadsheet cell	Spreadsheet computation (cell contents)
C5	PMT($B$1,A5,-($B$4-B5))+B5*$B$1
E5	D5/(1+$B$1)^A5
F5	PMT($B$1,A5,-SUM($E$5:E5))
G5	C5+F5

Table 5: A spreadsheet model for pw estimates for varied factor values

A	B	C	D	E
Most-likely values			2	
	Capital investment (F1)	$\$F_1$		
	Annual savings (F2)	$\$F_2$		
	Annual expenses (F3)	$\$F_3$		
	Useful life	n		
	MARR (F4)	I%		
Present worth estimates				
% Change in factor	F1	F2	F3	F4
-40%	$PW_{F1\ (60\%)}$	$PW_{F2\ (60\%)}$	$PW_{F3\ (60\%)}$	$PW_{F4\ (60\%)}$
-20%	$PW_{F1\ (80\%}$	$PW_{F2\ (80\%}$	$PW_{F3\ (80\%}$	$PW_{F4\ (80\%}$
0	$PW_{F1\ (100\%)}$	$PW_{F2\ (100\%)}$	$PW_{F3\ (100\%)}$	$PW_{F4\ (100\%)}$
20%	$PW_{F!\ (120\%)}$	$PW_{F2\ (120\%)}$	$PW_{F3\ (120\%)}$	$PW_{F4\ (120\%)}$
40%	$PW_{F1\ (140\%)}$	$PW_{F2\ (140\%)}$	$PW_{F3\ (140\%)}$	$PW_{F4\ (140\%)}$

Table 6: Computation of PW estimates for varied factor values

Spreadsheet cell	Spreadsheet computation (cell contents)
B9	-$C$2*(1+A9)+PV($C$6,$C$5,-($C$3-$C$4))
C9	-$C$2+PV($C$6,$C$5,-($C$3*(1+A9)-$C$4))
D9	-$C$2+PV($C$6,$C$5,-($C$3-$C$4*(1+A9))
E9	-$C$2+PV($C$6(1+A9),$C$5,-($C$3-$C$4))

RESULTS AND ANALYSIS

Costs data: Various costs for the 84-K001/2/3 air compressors, air-cooled rotary screw air compressor and water-cooled centrifugal air compressor were estimated and tabulated in Table 7-9, respectively. The minimum attractive rate of return was 10.03% per year and it was based on weighted-average cost of capital.

Table 7: Costs estimates for existing 84-K001/2/3 air compressors

	Description	Amount (RM)	Notes
Capital investment			
Equipment cost		0.00	
Engineering and construction		0.00	
Operating and maintenance costs			
Maintenance/overhaul costs	Lube oil and filters	12,000.00	cost @ EOY1, annual
	Major overhaul	158,950.00	cost @ EOY1; once in 6 years
	Major services	75,000.00	cost @ EOY1; once in 2 years
Operation cost	Electricity consumption	1,400,960.00	cost @ EOY1; annual
	Water consumption	13,824.00	cost @ EOY1; annual
Labor cost		91,242.00	cost @ EOY1; annual
Insurance premium		9,746.45	cost @ EOY1; annual

Table 8: Costs estimates for air-cooled rotary screw air compressor

	Description	Amount (RM)	Notes
Capital investment			
Equipment cost		1,917,640.00	
Engineering and construction		575,292.00	
Operating and maintenance costs			
Maintenance/overhaul costs	Lube oil and filters	12,000.00	cost @ EOY1; annual
	Compressor air ends (1st stage)	454,410.00	cost @ EOY1; once in 7 years
	Compressor air ends (2nd stage)	636,174.00	cost @ EOY1; once in 5 years
	Replacement of air coolers	60,000.00	cost @ EOY1; once in 5 years
Operation cost	Electricity consumption	723,360.00	cost @ EOY1; annual
Labor cost		91,242.00	cost @ EOY1; annual
Insurance premium		4,794.10	cost @ EOY1; annual

Table 9: Costs estimates for water-cooled centrifugal air compressor

	Description	Amount (RM)	Notes
Capital investment			
Equipment cost		3,417,833.00	
Engineering and construction		1,025,349.90	
Operating and maintenance costs			
Maintenance/overhaul costs	Lube oil and filters	12,000.00	cost @ EOY1; annual
	Bearing replacement	306,000.00	cost @ EOY1; once in 6 years
	Switchgear servicing	30,000.00	cost @ EOY1; once in 2 years
	Transformer servicing	9,000.00	cost @ EOY1; once in 6 years
Operation cost	Electricity consumption	696,919.17	cost @ EOY1; annual
	Water consumption	10,368.00	cost @ EOY1; annual
Labor cost		91,242.00	cost @ EOY1; annual
Insurance premium		8,544.58	cost @ EOY1; annual

The capital investment includes costs of engineering, procurement, construction, commissioning and other auxiliary equipment and installation. The engineering and construction costs were estimated at 30% of the total equipment costs.

The operation and maintenance costs consist of the costs of labor, maintenance, operating and insurance. The labor costs that include salary and benefits increase by eight percent per annum.

The maintenance cost of the compressors increased by four percent every year. The cost of insurance was based on 0.25% of the cost of the new equipment. The insurance charges increased by 0.6% per year.

Net present worth (PW): The net present worth of all associated cash flows for existing 84-K001/2/3 air compressors, air-cooled rotary screw air compressor and water-cooled centrifugal air compressor were computed. In this calculation, discounted costs excluding any revenues were considered. The objective is to compare costs rather than profitability (Schaber *et al*., 2011). The net PW for 84-K001/2/3 air compressors is (RM15,856,816), net PW for air-cooled rotary screw air compressor is (RM11,359,157) and net PW for water-cooled centrifugal air compressor is (RM12,458,086). In terms of costs, the PW of the existing air compressors is the highest. It is 20% higher than water-cooled centrifugal compressor and 28% more than air-cooled rotary screw compressor. Comparatively, air-cooled rotary screw type is the lowest in terms of costs.

Equivalent uniform annual costs (EUAC): EUAC for each air compressor is calculated and the results are graphically illustrated in Fig. 2. The air-cooled rotary screw air compressor has the lowest EUAC followed by water-cooled centrifugal air compressor and existing 84-K001/2/3 air compressors.

Breakeven analysis for mutually exclusive alternatives: Figure 3 shows the breakeven chart of the rotary and centrifugal air compressors. The rotary compressor will breakeven at 4 years while centrifugal compressor will breakeven at 7 years. By the calculation, comparatively the investment in the rotary compressor will generate cost savings to the company from the fifth year onwards until the end of the fifteen years study period.

Sensitivity analysis: Based on the above decision, sensitivity analysis is conducted for the air-cooled rotary screw compressor only. Figure 4 shows the sensitivity plot which reveals the effect of changes in three factors namely capital investment, labour cost and operation cost on the PW of the rotary compressor. These factors were chosen as the magnitude of the cash flows was comparatively larger than the other factors. The value of highly favourable PW occurs at the common intersection point of the percent deviation graphs for the three separate factors. The

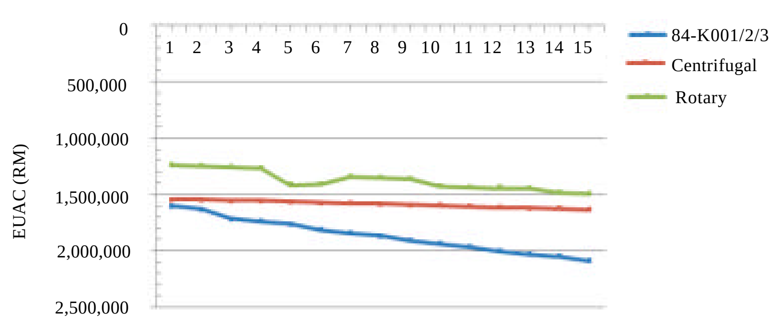

Fig. 2: Plot of cumulative euac for 84-K001/2/3, rotary and centrifugal air compressors

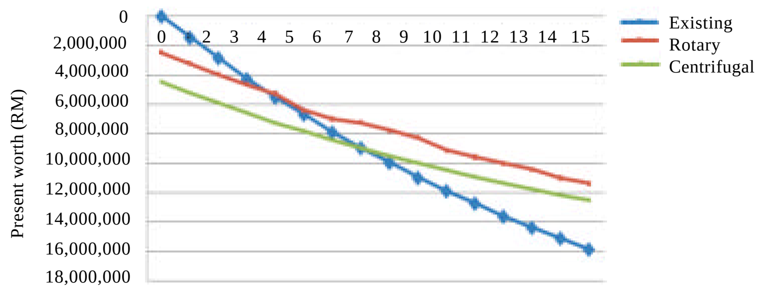

Fig. 3: Breakeven chart for three mutuallyexclusive alternatives

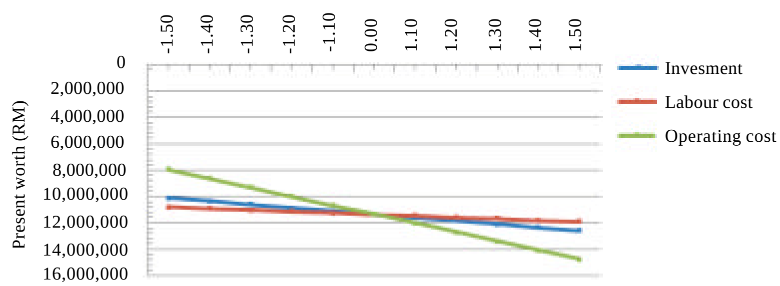

Fig. 4: Sensitivity plot of rotary screw air compressor

relative degree of sensitivity of the PW to each factor is indicated by the slope of the lines. It is evident that the steeper the slope of the line, the more sensitive the PW to this factor.

DISCUSSION

The net PW for 84-K001/2/3 air compressors is (RM 15,856,816), net PW for air-cooled rotary screw air compressor is (RM 11,359,157) and net PW for water-cooled centrifugal air compressor is (RM 12,458,086). Obviously, the existing air compressors have the largest negative net PW in comparison with the proposed new units. The air-cooled rotary screw compressor has the lowest negative net PW due to the fact that the capital investment and annual net cash flows were low. Therefore, it is recommended that the existing air compressors to be replaced with air-cooled rotary screw compressor immediately. A net PW cost saving of RM 4,497,659 is expected if the company implement this recommendation.

The results of EUAC analysis further support the decision to replace the existing 84-K001/2/3 with air-cooled rotary screw air compressor. The air-cooled rotary air compressor has the lowest EUAC throughout the 15 years useful life being considered. Breakeven analysis on the three mutually exclusive alternatives showed that the air-cooled rotary air compressor would be more economical than the water-cooled centrifugal air compressor as a replacement alternative for the existing 84-K001/2/3 air compressors. This finding further supports the earlier decision to replace the existing air compressors with air-cooled rotary air compressor. The quantitative analyses favor air-cooled rotary screw type for costs consideration in ensuring low ownership cost of the asset that produces one of the most expensive energy source in the production process (Yuan *et al*., 2006).

Finally, as the rotary compressor is the most economical option, a sensitivity analysis is carried out. It provides the evident that the PW of the air-cooled rotary air compressor is quite sensitive to its capital investment as indicated by the slope of the sensitivity plot. However, it is insensitive to the maintenance labour cost and operating cost.

CONCLUSION

The net PW, EUAC, breakeven and sensitivity analysis that were carried out have provided useful information in facilitating engineers and managers in deciding the replacement of the existing 84-K001/2/3 air compressors with air-cooled rotary air compressor. Based on the results of the analysis, it is recommended that the replacement be carried out immediately to ensure plant reliability is sustained for the next 15 years. This is in alignment with the company's operation strategy to have high asset reliability and performance. Furthermore, the decision will generate cost saving of RM 4,497,659 for the 15 years duration being considered at MARR of 10.03% per year. By conducting a comprehensive assessment and evaluation, potential problems can be identified. This will significantly mitigate any uncertainties in the replacement decision analysis. Having said that, the above were purely based on economic perspectives. No non-monetary factors were being considered.

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