AN ANALYSIS OF A GUIDANCE FOR REPLACEMENT OF MACHINES

Abstract

An O.R. Tool suggests the period after which a machine has to be replaced to get a minimum "Annual Average Cost" (AAC). The AAC consists of investment and relevant running costs that change during the life of the machine. A simple version of the model is analysed in detail.

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INTRODUCTION:

In India, replacement of machines is usually delayed. Often, there is a confusion as to when to replace machines. The Machine Replacement Model suggests the time of replacement by considering all the relevant costs (that includes the investment cost) that change with the ageing of the machine. Late replacement of machines, results in higher average annual cost (AAC). Of many cases of a machine replacement, only the following few are discussed in this article.

a. Machine replacement of a similar machine at the same (purchased) price

b. A case considering the time value of money.

The first case is analysed in detail, to get the nuances of the machine-replacement model.

MACHINE REPLACEMENT MODEL.

The Machine replacement model considers a (total) cost that consists of: (a) investment cost(**P**), (b) Resale (**RS**) or scrap value of the machine, and (c)the running cost(**RC**). The AAC is calculated for any year" n" of the machine usage as:

[(P-RS) + (Cumu.Running Cost at the end of Yr-"n")]/"n

Situation-1: Machine Purchase Price (P) = Rs120, 000. Decision Horizon: 10 Years

a) **(Re-sale Value (RSV):** Reduction from the Purchase Price **(P)** at the year-end from Yr1 to Yr10 is given in percentage and shown against the values a.b.c…i.& j. RSV is an income and is shown as "negative expenses" in the tables. RSV is a function of **"P",** as higher the "**P**", higher will be the RSV.

TABLE-1 RESALE VALUE(RSV)

Yr-1	Yr-2	Yr-3	Yr-4	Yr-5	Yr-6	Yr-7	Yr-8	Yr-9	Yr-10
a=5	b=5.5	c=6.25	d=7.25	e=8.5	f=10	g=11.75	h=13.75	i=16.0	j=18.5
0.9500P	0.9450P	0.9375P	0.9275P	0.9150P	0.9000P	0.8825P	0.8625P	0.8400P	0.8150P

Row-3 shows the RSV in terms of**(P)**. Eg: For Yr-3:(1-0.0625)P=0.9375P. Note that, as the M/c machine , there is more reduction in RSV.

b) **R&M cost** (a function of "P"): The increase in R&M cost, from the Pr.Yr is in Row-2.

TABLE-2

REPAIRS & MAINTENANCE (R&M) COST: FOR YR1=0.01500P I.E.1.5% OF P

Yr2	Yr3	Yr4	Yr5	Yr6	Yr7	Yr8	Yr9	Yr10
0.00125P	0.00125P	0.00150P	0.00150P	0.00175P	0.00200P	0.00225P	0.00250P	0.00350P

0.01625P	0.01750P	0.01900P	0.02050P	0.02225P	0.02425P	0.02650P	0.02900P	0.03250P

The last row is the R&M cost for the year, after considering the increment shown in Row-2. Note the increase in the rate of increase in the cost. Eg:For Yr-3: Last Yr fig in last Row + increment in Row-2. =0.01625+0.00125=0.01750 .

(c) Other Costs like, power, maint. wages, defects, speed reduction etc. are "relevant costs", as they vary with ageing of the machine, but they are not function of "**P**". Hence only the absolute values are shown in the table below.

TABLE-3

THE OTHER COSTS (IN RS. 000S)

Yr-→	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Power	4	4	4	4	4	4.1	4.1	4.1	4.2	4.4
Maint.Wages	5	5	5	5	5	5.1	5.1	5.1	5.2	5.4
Q'lty&Others	2.5	2.5	2.5	2.5	2.5	2.6	2.6	2.6	2.6	2.7
Total	11.5	11.5	11.5	11.5	11.5	11.8	11.8	11.8	12.0	12.5

From the above details, one can decide the period after which the machine is to be replaced.

(d) The values of RSV and various costs are reproduced with more details in Tables-4&5 below.

TABLE-4

RE-SALE VALUE AND R&M COST PER MACHINE

Figs in (000s)

Year----->	**1**	**2**	**3**	**4**	**5-→**
Re sale Value %P (from Table-1)	0.9500	0.9450	0.9375	0.9275	0.9150
Resale (Rs)K for P=120K	114	113.4	112.5	111.3	109.8
R&M %of(P)[from Table-2]	0.015	0.01625	0.01750	0.0190	0.02050
R&M Rs(K) for P=120K	1.8	1.95	2.10	2.28	2.46
Year----->	**→6**	**7**	**8**	**9**	**10**
Re sale Value %P (From Table-1)	0.9	0.8825	0.8625	0.84	0.8150
Resale (Rs)K	108	105.9	103.5	100.8	97.8
R&M %of (P) [from Table-2]	0.02225	0.02425	0.02650	0.02900	0.03250
R&M Rs(K)	2.67	2.91	3.18	3.48	3.9

TABLE-5

DETAILS OF RUNNING COST

Figs in Rs.(000s)

Yr	**Power@**	**Maint.Wage@**	**R&M(*)**	**Q'lty & Others@**	**Total**
1	4	5	1.8	2.5	13.3
2	4	5	1.95	2.5	13.45
3	4	5	2.10	2.5	13.6
4	4	5	2.28	2.5	13.78
5	4	5	2.46	2.5	13.96
6	4.1	5.1	2.67	2.6	14.47
7	4.1	5.1	2.91	2.6	14.71
8	4.1	5.1	3.18	2.6	14.98
9	4.2	5.2	3.48	2.6	15.48
10	4.4	5.4	3.9	2.7	16.4

@Vide Table-3

* Vide Table-4-Row-5

TABLE-6

CALCULATIONS TO DETERMINE AAC.

For P=120K, RS is from Tab4 row3. Figs in(000s)

1	2	3	4	5=2+4	6=(5)/(1)	7=(Prev Row-Cur,Row) of Col.5	Remarks
Yr	P-RS	Running Cost (Tab5)	Cumu.Running Cost	Total Cost(up to the year)	AAC	Tot.Cost for the Yr	
1	6	13.3	13.3	19.3	19.3	19.3	See NB(1)
2	6.6	13.45	26.75	33.35	16.68	14.05	See NB(2)
3	7.5	13.6	40.35	47.85	15.95	14.50	See NB(3)
4	8.7	13.78	54.13	62.83	15.71	14.98	See NB(4)
5	**10.2**	**13.96**	**68.09**	**78.29**	**15.66**	15.46	See NB(5)
6	12	14.47	82.56	94.56	15.76	16.27	See NB(6)
7	14.1	14.71	97.27	111.37	15.91	16.81	
8	16.5	14.98	112.25	128.75	16.09	17.38	
9	19.2	15.48	127.73	146.93	16.33	18.18	
10	22.2	16.4	144.13	166.33	16.63	19.40	

The total cost for any year shown in Col-7, is obtained from Col-5. For example, the total cost for the Yr-4 =Total cost up to the end of the Yr-4 (i.e.62.83) less the total cost up to the end of Yr-3 (i.e.47.85) =14.98.

Note that, there is *no decrease* in all the costs, as the machine ages. The segregation of costs- dependent on (P) and not dependent on (P), is done to find the impact of the purchase price on the replacement decision.

The replacement rule is: "Replace the machine immediately after the end of the year at which AAC is minimum", which happens, "When the total cost for the next year is more than the AAC for the year. The rule will be clear on following the below mentioned notes.

Note (1): The next yr (Yr-2) total cost of Rs14.05K is < the AAC (Rs19.3K) up to the Cur.Yr.(i.e.Yr-1)

Note 2: The next yr (Yr-3) total cost14.50 is < the AAC(16.68) up to the Cur.Yr (i.e.Yr-2)

Note 3: The next yr (Yr-4) total cost 14.98 is < the AAC (15.95) up to the Cur.Yr. (I.e.Yr-3)

Note 4: The next yr (Yr-5) total cost 13.96 is < the AAC (15.71) up to the Cur.Yr. (I.e.Yr-4)

Note 5: The next yr (Tr-6) total cost 16.27 is > the AAC (15.66) up to the(Cur.Yr. (i.e.Yr-5).

Therefore replace the machine immediately after the end of Yr-5. Note the AAC is also minimum at the end of the Yr-5.Note the difference in the two costs (16.27 &15.66) =Rs 0.6K

Note 6: The next yr (Yr-7) total cost 16.81 is > the AAC (15.76) up to the Cur.Yr. (i.e.Yr-6).Note the increases in the difference between the two costs (16.81-15.76=) 1.05,

The differences for the other years are:

Yr-7= (17.38-15.91=) 1.47, Yr-8= (18.18-16.09=) 2.09. Yr-9= (19.4-16.33=) 3.07 and the trend goes on. Thus, after reaching the minimum AAC at the end of Yr-5, AAC continues to increase (in fact at a faster rate) as the year passes. Thus, the minimum AAC at the end of Yr-5 is unique. When the increase in the costs is erratic (i.e., sometimes decreasing, sometimes increasing) there will NOT be a unique minimum AAC.

The above suggestion for machine replacement indicates that the organisation, if it replaces the existing machine immediately after the end of Yr-5, with another (new) machine at the same purchase price (P) and incur the same RSV as well as the running costs(RC) as before and thereby, incur the same total cost, and if at the end of Yr-5,get the new machine replaced-in a similar manner, then, the AAC for every year, will be Rs15,660 or the total cost in the entire block of five years will be (5X15660)= Rs.78,290. The pattern repeats and an AAC of Rs15,660 p.a. is incurred perpetually. (If the time value of money is ignored).

WHAT HAPPENS IF THE REPLACEMENT IS NOT AS PER THE RECOMMENDATION

1. Suppose, the replacement is done after the end of the sixth year, the AAC for every year will be Rs. 15,760 which is >Rs.15,660 if replaced at the end of Yr-5. For a reference period of 30 years, when replaced at the end of 6th year, there will be five replacements- each with a cost of 6X15760=Rs 94,560 for a block of six years. The total cost for 30 years will be=5X94560=Rs.472,800. During the same 30 year-period, if the machine is replaced once in five years (as per the recommendation), there will be six replacements

and the total cost will be 6X78,290=Rs.469,740.Thus replacing once in six years results in higher cost of (472,800-469,740=)Rs3, 060 for every six years.

2. Suppose, the replacement is done immediately after the end of the seventh year, the AAC for every year will be Rs.15, 910(I.e. >Rs.15, 660 for the recommended year) or Rs 111,370 for a block of seven years. For a block period of 35 years, there will be five replacements each with a cost of Rs 111,370 for a block of seven years. The total cost for 35 years will be=5X111370=Rs.556, 850. During the same 35 years, if the machine is replaced once in five years, there will be seven replacements and the total cost will be 7X78,290=Rs.548,030. Thus replacing once in seven years results in higher total cost of (556,850-548,030=)Rs8, 820 for every 7 years. Thus, as and when the replacement is delayed, the average cost incurred every year increases. But this may not happen when there is random or illogical occurrence of the various costs. (A similar calculation, for the early replacement of the machine can be done, but usually the replacement is delayed). To check whether there is no reduction in the AAC after a rise in the AAC, the calculations should be continued at least for five more years from the first minimum AAC and should confirm the trend in the increase in the AAC.

PRICE ESCALATION

EFFECT-SITUATION 1.

1. Replacement of a machine after some years at the same purchase price is unlikely in most cases, due to price escalation even for the same make of the machine. The higher purchase cost, changes the R&M and RSV(as they are dependent on the purchase price).But the "other running costs "are kept the same. The effect of higher purchase price on AAC of Rs140K,is shown in the following table.

   R&M cost for the 10 years:

   Rs2100, 2275, 2450, 2660, 2870, 3115, 3395, 3710, 4060 & 4550.

   RSV for the 10 years are:

   Rs(K)133,132.3,131.25,129.85,128.1,126.0,123.55,120.75, 117.6,&114.1

TABLE-7

CALCULATIONS TO FIND AAC WHEN THERE IS PRICE ESCALATION.

P=140K Figs in(000s)

1	2	3	4	5=2+4	6
Yr	**P-RS**	**Running Cost**	**Cumu.Running Cost**	**Total Cost**	**AAC=(5)/(1)**
1	7.00	13.600	13.600	20.600	20.6
2	7.70	13.775	27.375	35.075	17.538
3	8.75	13.950	41.325	50.075	16.692
4	10.15	14.160	55.485	65.635	16.409
5	**11.9**	**14.370**	**69.855**	**81.755**	**16.351**
6	14.0	14.915	84.770	98.770	16.462
7	16.45	15.195	99.965	116.415	16.631
8	19.25	15.510	115.475	134.725	16.841
9	22.4	16.060	131.535	153.935	17.104
10	25.9	17.050	148.585	174.485	17.449

(The new machine after installation should be replaced after five years)

2. The minimum AAC of the new machine is Rs.16, 351, indicating that higher replacement cost, increases the AAC. But, in this situation, the existing machine will not be replaced after the 5th year with a new machine for the reason given below.

3. Col-7 of Table-6 shows that the cost for Yr-6 is Rs16.27K and for Yr-7, it is Rs16. 81K. Therefore, there is no point in replacing the existing machine after the end of Yr-5 and incur every year, an average annual cost of Rs16.351K on the new machine with the same features. Further, for the existing machine, in the next year (Yr-7), the total cost is Rs16.81K, which is more than Rs16.351K of the new machine Therefore, after the end of Yr-6, the existing machine should be replaced with new machines of P=140K.

SITUATION-2. TIME VALUE OF MONEY

1. To get the time value of money, the present value of money to be spent or received in future is calculated. The present value of one Rupee spent after "n" years=(V_n) where V=1/(1+d) where, "d" is the discounting rate (or the interest rate) p.a. The decisive rule for machine replacement is," Replace the machine when [{P- (RS for the year(i)X(V) for the year" I")}+(Cumu.running cost for the year "i"X "V" for the year"i")]/ (Cumu. "V" for the Year"I") is minimum. The value of "I" indicates the year, which vary from 1 to "n". Here P=Purchase price and RS=Resale value. The running cost is assumed to be spent at the beginning of the year.
2. Consider the case as in Situation-1 but with some modifications.

   We get, for an interest or discount rate(d) of 5 per cent p.a, the discounting factor for different years as :V(i)=1/(1+d) and for d=0.05,the V(i) for the beginning of year 1 to 12 are: 1.000, 0.9524, 0.9070, 0.8638, 0.8227 ,0.7835, 0.7462, 0.7107, 0.6769, 0.6447, 0.6131, 0.5847.
3. Purchase price(P)=120K.For simplicity in calculation, RSV is taken to be zero for all the years.
4. The AAC as per this method will be less than the AAC of the earlier method. This is applicable for all the years. But, as we compare only the relative figures arrived from the same method, this method of calculation will NOT affect the decision on Replacement of a Machine.

TABLE-8
CALCULATIONS TO DETERMINE AAC

Figs in(000s)

1	2	3	4	5	6=(3)X(4)	7	8=(2)+(7)	9=(8)/(5)
Yr Begin	**P-(RSi)**	**Running Cost R(i)**	**Disc Rate V(i)**	**Cumu V(i)**	**R(i) X V(i)**	**Cumu R(i).V(i)**	**[P-RS(i)]+ Cumu Ri,Vi**	**AAC=(8)/ Cumu.Vi**
1	120	0	1	1	0	0	120	120
2	120	14	0.9524	1.9524	13.333	13.333	133.3333	68.29
3	120	15	0.9070	2.8594	13.605	26.9388	146.9388	51.39
4	120	16	0.8638	3.7232	13.821	40.7602	160.7602	43.18
5	120	18	0.8227	4.5459	14.804	55.5688	175.5688	38.62
6	120	20	0.7835	5.3294	15.617	71.2393	191.2393	35.88
7	120	22	0.7462	6.0756	16.417	87.6561	207.6561	34.18
8	120	25	0.7107	6.7863	17.767	105.4231	225.4231	33.22
9	120	28	0.6769	7.4632	18.952	124.3746	244.3746	32.74
10	**120**	**31**	**0.6447**	**8.1079**	**19.983**	**144.3575**	**264.3575**	**32.61**
11	120	35	0.6139	8.7217	21.487	165.8445	285.8445	32.77
12	120	39	0.5847	9.3064	22.802	188.6470	308.6470	33.17

Minimum AAC occurs in the beginning of Yr10 and therefore, the machine should be replaced in Year-10.

FACTS OF THE MODEL ON REPLACEMENT MACHINE

1. The Purchase price *minus* -RSV for any year, indicates the investment cost up to the year. In Situation-1, at the end of Yr-1, a resale value of Rs114K is realised; thus 120-114=6K is the cost of investment till the end of yr-1. At the end of Yr-2, a resale value of Rs113.4K is realised, thus 120-113.4=Rs 6.6K is the cost of investment till the end of Yr-2, i.e. the investment cost for the two years. The average investment cost p.a. at the end of two years= 6.6/2=Rs3.3K (p.a.) and so on for other years. The total cost shown in Col-6 indicates the investment cost up to the year plus the cumulative running cost incurred up to the year. When minimum AAC is reached in later years, the share of (P) in the AAC is < when minimum AAC is reached earlier.
2. The AAC for all the years will be low, if all the costs P & RC is low, and RSV is high. If (P) is high, then, the RSV will be high. The running cost should be low, to reduce the AAC. In addition, if the rise in the costs from RSV and RC, is less or if the increase is postponed to later years, then the increase in AAC can be postponed and thereby, minimum AAC can be obtained in later years.
3. *Running costs.* The Common running costs that change with the ageing are: (i) Wages of maintenance-team (often to handle more break downs), (ii) Power cost (that increase due to wear and tear of the machine, (

iii)R&M cost, that increases on ageing, (iv) Increase in defects and thus the revenue loss (taken as cost), (v) Reduction in the speed of the machines on ageing and thus the loss (taken as cost).

4. The R&M cost will be a small percentage of "P" in the initial years, but it increases over the years.

ANALYSIS OF AAC

1. What is important to note is that the rate of increase in the cost due to change in the RSV and RC, will never reduce. That is, the rate of increase, if it is say 5 per cent in the initial years i.e. when the machine is new, it cannot be less than 5 per cent when the machine is old.
2. Changes in the average value of (P) p.a:

   "P" is the one- time fixed expense incurred in the beginning of the Yr-1. For a given "P", the average value of (P)=P/No: of yrs cannot be changed. Thus, the drop in the average value over the years cannot also be changed. The drop is sharp initially (50 per cent of P in Yr-2), reduces every year and reaches the minimum at the end of the last year.
3. Drop in resale value:

   There will always be reduction in the RSV of the machine due to its ageing. As the RSV is considered as revenue, the decrease in the revenue may be taken as "increase in the cost".

   In the initial years, the drop in the average cost of "P" is more, and drop in the RSV is expected to be low. During the same (initial) period, the running costs are also low as the machine is new. For any year, if the sum of, (increase in the average RC p.a.) + (the increase in cost due to the average drop p.a. in the RS) is less than the reduction in the (average cost of "P"p.a,). then, there will be drop in AAC w.r.t. the previous year, otherwise not This happens without much effort, in the initial years. But, as years pass, the drop in the average cost of "P" p.a. becomes smaller, the drop in the RSV becomes larger and during the same period, the running cost also increases more due to the ageing of the machine. Thus, the drop in AAC is possible in later years, only when the drop in the RSV and the rise in the RC are very small years, which is very difficult when the machine is old.

CONDITIONS FOR THE AAC TO REDUCE W.R.T. THE PREVIOUS YEAR

1. RSV, R&M and other costs can increase above the prescribed limit and increase the AAC in the subsequent year. For a given "P", one can find, the maximum allowable increase in the R&M cost to ensure, no increase in the AAC in the subsequent year.

   Example: For AAC_2 to be less than AAC_1, calculations available with the author show that, when the R&M cost is less than 6 per cent of (P=120K) in Yr2, then, AAC_2 will be < AAC_1, otherwise not. *Check:* When R&M cost is 6.5 per cent of "P". R&M cost is (120*0.065=) Rs7.8K and the total cost is 11.5+7.8=Rs 19.3K.The cumulative running cost=13.3+19.3=Rs32.6K. where 13.3 is the cumulative running cost till the end of Yr-1. P-RS at the end of Yr2= Rs.6.6K. (vide Table-6). Then, the total cost will be=6.6+32.6=Rs39.2K and the AAC_2 will be =39.2/2=Rs19.6K (which is > the AAC_1 of Rs19.3K). The actual R&M cost in Yr2 was 1.625 per cent of (P) which is < the maximum allowed limit of 6 per cent and therefore the actual AAC_2(16.68) was <AAC_1. (19.3)
2. Take year 5 as yet another example. For the, AAC_5 to be less than AAC4.calculations available with the author show that, when the R&M cost is less than 2.256 per cent of (P) then, AAC_5 will be < AAC4;, otherwise not. Check: In the example R&M cost in Yr_5 was 2.05 of P. Therefore, AAC_5<AAC4. Suppose X=2.5 per cent (or)R&M=(120KX0.025=) RS3,000,(or) Total running cost=Rs11.5K+3K= Rs14,500. As AAC_5=[(P-RS_5)+CRC_4]/4=[120K-(0.9150*120K) +54,130 +14,500]/5=[78830]/5=15,766 which is>AAC_4(of Rs 15710). Rs54,130 is the CRC for Yr 4.
3. It may be noted that the permissible limit for increase in the R&M cost, reduces when the year passes. In Yr.1 it was 6 per cent, Yr-3=3.66(not shown above), Yr-5=2.256 and so on. But as years pass, the R&M cost increases. Due to the dwindling permissible limit in later years, unless the increase in the R&M cost is very much controlled, the AAC will increase, triggering an advice for replacement of the machine.

CONCLUSION

The use of machine replacement tool requires estimates many costs/ revenues like, cost equivalent of: (a) reduction in speed of the machine;(b) increase in defects; (c) increase in maintenance, staff; (d) Increase in power cost; (e) Increase in R&M cost and (f) Resale value for each year of the machine operation. It also assumes increase in cost/reduction in revenue, over the period of usage. The model is a useful tool in objectively deciding the replacement period. It also quantifies the additional cost, if replacement is not done, as per the suggestion. The model "Time Value of Money", is more relevant for all its practical applications. MA

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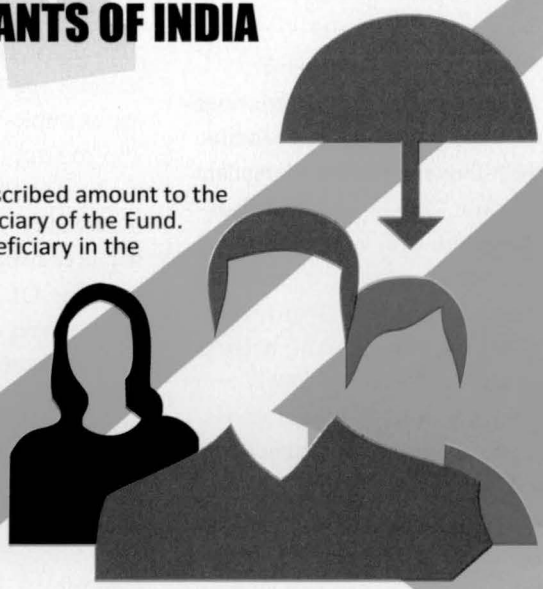

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