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Need for incorporating reliability and availability in payback calculations

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ABSTRACT

Purpose: The paper presents a method of payback calculation based on the process valuation model by incorporating reliability and availability. The paper also presents a comparison of calculation of payback periods using the conventional method with the method that uses the valuation model.
Design/methodology/approach: The value of the system is arrived by considering the present worth of expected future cash flows. The model takes into consideration the system availability, in addition to the other cost elements like investment cost, and maintenance as well as operating cost.
Findings: Calculation of pay back using valuation model was compared with the conventional method. The valuation model method proves to be a better tool in making safe decisions.
Practical implications: In order to arrive at the economic feasibility of the new proposal the benefits that can be derived over the lifetime as well as the operating and maintenance costs are compared with the investment to be made. However, quite often the change in reliability of the proposed new design as a result of the change in system configuration or change in system components or both of these factors are not taken into consideration.
Originality/value: Any new proposal for modification of the existing process or equipments should prove itself to be economically feasible for gaining acceptance for implementation.
Keywords: Availability; Breakeven availability; Reliability; System value; Change in system value

1. Introduction

The process plants that are operated on continuous basis consume large quantities of energy. Considering the fact that the energy demand is overtaking the energy production at a very rapid rate it is important that top priority be given for energy conservation programs. Keeping this in view, most of the process systems are either modified or are in state of modification for optimizing the energy use and improving the energy efficiency. However, whenever a system is modified with a view for improving energy efficiency, reliability and availability aspects also has to be taken into consideration. Plant availability is a critical driver for the economic performance of a plant [2]. With more and more emphasis given for energy conservation programs and policies most of the existing process systems are modified or redesigned with an objective for improving the energy efficiency. Often the system modifications result in a change in system configuration there by affecting the system reliability. It is important that system modifications for improving energy efficiency should not be at the cost of reliability. While designing the systems, often the focus is on immediate demands of the equipment and the broader issue of how the system parameters affect the equipment is overlooked [8]. It is essential to recognize that process efficiency and reliability are equally important.

Reliability can be defined as the probability that an item can perform a required function for a specified period of time under the specified operating conditions [1, 7, 10]. Reliability of an individual component in terms of failure rate can be expressed as:

$$R(t) = e^{-\int_0^t Z(t)dt} \quad (1)$$

Key parameters describing reliability are mean time to failure, mean time between/before repairs, mean life of components, failure rate and the maximum number of failures in a specific time-interval [10]. For a component with a constant failure rate Equation (1) reduces to:

$$R(t) = e^{-\lambda t} \tag{2}$$

Equation (2) is generally used for the calculation of component reliabilities for a given system. In reality, even though this holds good only in-between the period of infant mortality and wear-out, it is often a reasonably good assumption as this time frame is equal to almost the entire lifetime of any equipment. The constant failure rate model is widely used in the literature to reduce the computational burden of the resulting problem because the parameter MTBF which can be obtained from Equation (3) becomes time-independent in this case [2].

$$MTBF = \int_0^\infty R(t)dt = \int_0^\infty e^{-\lambda t}dt = \frac{1}{\lambda} \tag{3}$$

Similarly, with a constant mean repair rate, MTTR can be expressed as:

$$MTTR = \frac{1}{\mu} \tag{4}$$

For a process system reliability may be the product of many different reliability terms, such as

$$R(t) = R(t)_{boiler} \times R(t)_{feedwaterpump} \times R(t)_{piping} \times etc. \tag{5}$$

Similarly, process system availability can be expressed as the product of component availabilities.

Similar to reliability, availability of the process system can be expressed as a function of component availabilities. With the increase of number of essential components in the system, the system reliability will decrease and to achieve high system reliability component reliability values should be very high.

Typical approaches to achieve high system reliability are: (1) increasing the reliability of system components, and (2) using redundant components in various subsystems in the system [3,6,11]. The modification of an existing system with a view to improve energy efficiency should consider these factors. The pay back period calculations with regard to the modified system should also consider these factors. The conventional approach involves comparing the total life-cycle cost (LCC) of the proposed new design with the LCC for a baseline design [4]. The payback period equation can be expressed as:

$$Payback_{option} = \frac{Equipment\ \cos t_{option} - Equipment\ \cos t_{base}}{Operation\ \cos t_{base} - Operation\ \cos t_{option}} \tag{6}$$

where, base is the base case design, and option is the design option being considered. It is very much evident from the Equation (6) that the conventional method does not consider the change in reliability and availability of the new design. The paper presents a method of payback calculation by taking these aspects, that is, reliability and availability into consideration. The paper also brings out the variation in calculations of the pay back period when reliability and availability are considered.

2. Process valuation model

This section describes the system valuation model. The value of the system is arrived by considering the present worth of expected future cash flows. The model takes into consideration the system availability, in addition to the other cost elements like investment cost, and maintenance as well as operating cost. The cash flow model for system valuation is shown in Fig. 1. The model is based on the following assumptions:

- Process components are assumed to have a constant failure rate as well as a constant repair rate;
- Availability under consideration is steady state availability;
- Interest rate is constant throughout;
- Depreciation of the plant is not considered.

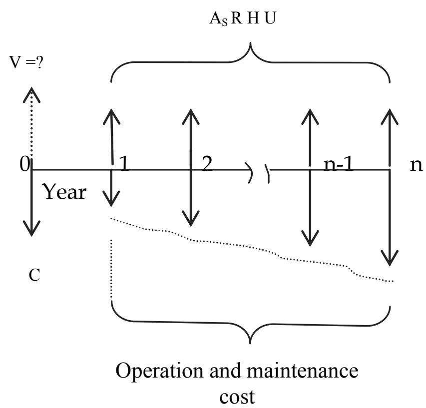

Fig. 1. System valuation model

With reference to the cash flow model shown in Fig. 1, the process system value can be expressed as:

$$V = A_S RHU\ (P/A,i,n) - C - A_S O_S \left[\frac{1-(1+k)^n(1+i)^{-n}}{i-k}\right] \tag{7}$$

The valuation Equation (7) can be used only for cases where $i \neq k$ and when $i = k$ the equation will get modified as:

$$V = A_S RHU(P/A,i,n) - C - \frac{nA_S O_S}{1+i} \tag{8}$$

The quantity (P/A, i, n) in the Equation (8) is the uniform series present worth factor [5] and can be obtained as:

$$(P/A,i,n) = \frac{(1+i)^n - 1}{i(1+i)^n} \tag{9}$$

Whenever a process system is to be modified for energy savings, it is important to know the expected change in system value. In this case, the investment for modification, expected annual savings due to modification as well as the change in system availability has to be taken into consideration. Change in process availability results from the change in system configuration. The change in process value can be expressed as:

$$V_C = [A_m(RHU - O_m) - A_S(RHU - O_S)](P/A,i,n) - C_m \tag{10}$$

The pay back period corresponds to the value of n that makes $V_C = 0$.

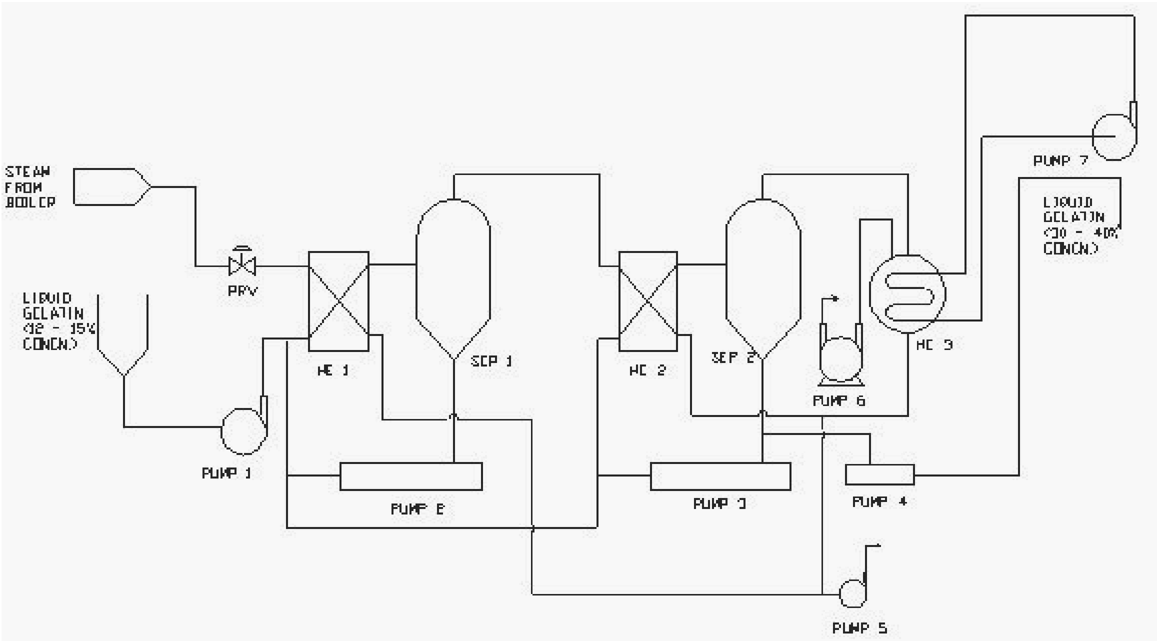

Fig. 2. Concentrator part of the gelatin plant

3. Process description and modification

In order to study the impact of system modification the analysis was conducted in a concentrator part of a gelatin manufacturing plant that was modified for improving energy efficiency. The concentrator part of a gelatin plant is shown in Fig. 2 and the corresponding failure data is given in Table 1. Concentration of the liquid gelatin is achieved by means of a three stage evaporative process. Dilute gelatin solution is received in a feed tank. A circulation stream is maintained through the first effect of the concentrator consisting of heat exchanger HE 1 and separator SEP 1 by the circulation pump 2. Gelatin solution from feed tank is pumped to this circulation stream by pump 1. This solution is heated by steam coming from steam header through pressure reducing valve (PRV). The heated solution gets concentrated by the evaporation of water. A part of this medium concentration gelatin is fed to the circulation stream of second effect of the evaporator. Again the second effect of the concentrator consists of heat exchanger HE 2 and separator SEP 2 and circulation is maintained by pump 3. The feeding quantity to first effect is balanced with the sum of water quantity evaporated and gelatin quantity bled out. The heating medium for second evaporator is the vapour generated by the first effect. In second effect evaporated vapour is removed from separator to a condenser HE 3, where it is condensed. Here the concentration maintained is higher and part of this concentrated gelatin solution is taken out by pump 4 and fed to next section. The steam condensate together with the vapour condensates are removed from system by pump 5. All this evaporation is carried out at vacuum pressure so as to keep temperatures down. This vacuum is maintained by pump 6 by removing non condensable gases from condenser. The heat rejected at condenser is removed by circulating water pumped by pump 7. The heat required for the evaporative process is supplied by steam which is generated at a pressure of 40 kgf/cm^2 and brought down to 3 kgf/cm^2 by means of a pressure reduction valve (PRV).

Table 1.
Failure data for the concentrator part of the gelatin plant

Component No.	Component	MTBF (hours)	MTTR (hours)
1	Hot excharger 1	4020	8
2	Hot excharger 1	4510	8
3	Hot excharger 1	4480	8
4	Separator 1	5540	8
5	Separator 2	5580	8
6	Pump 1	4500	6
7	Pump 2	5100	6
8	Pump 3	5063	6
9	Pump 4	5190	4
10	Pump 5	4409	4
11	Pump 6	4510	4
12	Pump 7	4409	4
13	Boiler feed water pump	6206	4
14	Boiler	6900	24
15	PRV	6000	4

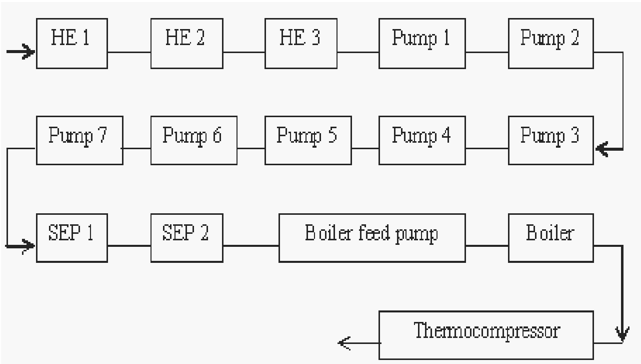

Fig. 3. RBD corresponding to the modified gelatin plant

The modification for improvement in energy efficiency was carried out by introduction of a thermocompressor instead of PRV. Part of the vapour generated in first effect at low pressure is sucked by the thermocompressor to generate medium pressure steam. This process is powered by high pressure steam that is the motive force from steam header. The modification costed about $ 4 lakhs including the cost of thermocompressor and replacement of old boiler by a new one. The MTBF and MTTR of the new boiler are 4500 and 18 hours respectively, and that of the thermocompressor 6000 and 36 hours respectively. The estimated annual savings as a result of the decrease in operating cost is estimated to be around $ 2.8 lakhs. The RBD for the modified process system is shown in Fig. 3.

4. Results and discussion

The operation and maintenance cost before and after modification corresponding to the system operation period of 7000 hours as well as the change in process system value calculation is shown in Table 2. A simple pay back analysis by using Equation (6) will show that the pay back can be achieved in 1.43 years or 17 months. In order to accommodate the production loss (or gain) as a result of modification resulting from change in system configuration the model can be used and the pay back period can be arrived by using Equation (10). The reduction in operation cost results from the reduction in fuel consumption and the corresponding energy calculations are shown in Table 3. The steam system efficiency was obtained using the method proposed by Siddhartha Bhatt [11].

As per the model the pay back period works out to be 1.72 years or 20.5 months. The variation of change in process value after modification as a function of system life is shown in Fig. 4. The variation of reliability and availability in relation with change in energy efficiency is in the opposite direction. Even though there is a decrease in availability and reliability of the process system resulting in production loss after modification the change in process value is very much favourable and this is because of the fact that the magnitude of the monetary benefit resulting from increase in energy efficiency is more than that of the production loss.

Table 2.
Calculates of change in process system value and playback

Expected life of the system, n(Years)	15
System operating hours in a year	7000
Unit price of the output, U(Rs/$)	1
Production rate, R(kg/hr)	1215
Cost of modification, C_m ($)	400000
Operation and maintenance cost before modification corresponding to system operating hours in a year, O_s($/year)	8045908
Operation and maintenance cost after modification corresponding to system operating hours in a year, O_m($/year)	7765728
System availability before modification A_s	0.979897466
System availability after modification A_m	0.974196001
(P/A,i,n), corresponding to the life of the system	6.8108
Change in Process Value, V_c for a system life of 15 years ($)	1441199.64
Payback Period, b (years)	1.724881

Table 3.
Energy and efficiency calculations for concentrator part

Particulars	Before Modification	After Modification
Steam rate (kg/hr)	1250	825
Energy of the feed water at the boiler inlet (kW), Q_w	123.9504	81.787
Energy of the Steam at the boiler autlet (kW), Q_b	971.8128	635.9816
Fuel supplied (kg/hr)	97.6	64.4
Energy of the fuel suppliedto the boiler (kW), Q_f	1081.733	713.7667
Boiler efficiency, η_b	78.38%	77.64%
Energy loss in the line due to heat dissipation from t	266	146
Efficiency of the steam line η_l	72.63%	77.64%
Theoretical useful energy required to accomplish the given task (kW), Q_u	250	250
Useful task efficiency, η_u	35.42%	55.13%
Energy in the condensate recovered from the condensate return. (kW) Q_τ	123.95	81.79
Factor of unrecovered condensate η_τ	87.24%	87.14%
Overall steam system efficiency	23.11%	35.02%

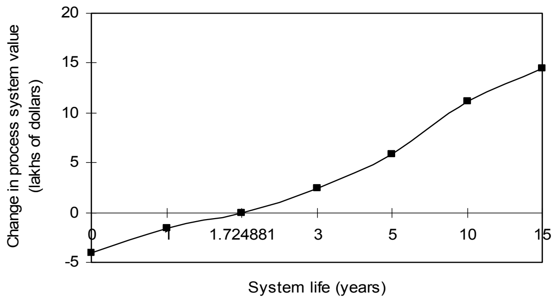

Fig. 4. Change in process value with system life for gelatin plant

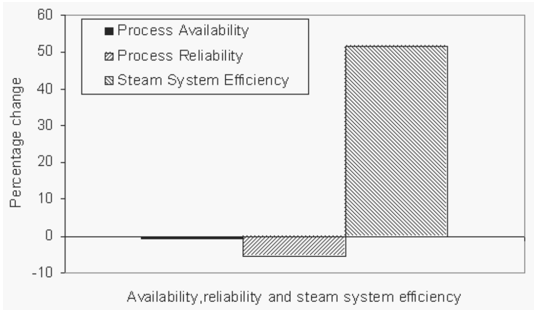

Fig. 5. Impact of modification on availability, reliability and energy efficiency

This also indicates the importance of considering the relative magnitude of the change in reliability and energy efficiency in decision making. With the increase of energy efficiency the operating cost will come down. However, operating cost itself is related with availability. Also, corresponding to the decrease in availability there will be a reduction in the production and there by revenue. The pay back period is calculated by considering these factors. Fig. 5 shows the impact of modification on reliability, availability and energy efficiency.

The model was validated using the actual production data from plant. Table 4 gives the actual production figures obtained from the plant after modification. Monthly production and operating cost figures are compared with the average values for the year before modification. It can be seen that after modification the change in production for most of the months is negative. However, the relative magnitude of loss due to decrease in production is less compared to the savings in the operating cost. The pay back period as per the actual data is 19 months. Table 5 gives a measure of the error involved in calculations of the pay back using conventional method and the valuation model. The valuation model method proves to be a better tool in making safe decisions.

Table 4.
Actual production figures

Month and year	Monthly production after modification, (kg)	Change in production, ($)	Decrease in operation and maintenance cost after modification, ($)	Net Benefit, ($)
Oct 4	707130	-7210	29282. 3	22072.32
Nov	707130	-7210	29282. 3	22072.32
Dec	713763.9	-576.1	23393.3	22817.2
Jan 05	713836.8	-503.2	23328.6	22825.4
Feb	699840	-14500	35753.8	21253.76
Mar	710775	-3565	26046.6	22481.6
Apr	727542	13202	11162.3	24364.28
May	729000	14660	9868	24528
Jun	670680	-43660	61639.5	17979.52
Jul	641520	-72820	87525.	314705.28
Aug	656100	-58240	74582.4	16342.4
Sept	692550	-21790	42225.2	20435.2
Oct	692550	-21790	42225.2	20435.2
Nov	707130	-7210	29282.3	22072.32
Dec	691821	-22519	42782.3	20353.34
Jan 06	692550	-21790	42225.2	20435.2
Feb	703485	-10855	23518	21663.04
Mar	677970	-36370	55168.1	18798.08
Apr(19)	729000	14660	9868	24528
			total	400162.5

Table 5.
Payback comparison using conventional and valuation model

Method	Payback	% Error
Conventional method (Equation 6)	17 months	-10.5%
Valuation model (Equation 10)	20.5 months	7.8%
Actual plant data	19 months	-

5. Conclusions

In this paper the importance of considering process reliability and availability in pay back calculations was brought out. The case of an industrial situation wherein the modification has resulted in decrease in reliability and availability was considered. Calculation of pay back using valuation model was compared with the conventional method. A measure of the relative error involved in calculations was also presented.

Nomenclature

A/P	annual rate given the present value
A_i	steady state availability
A_m	process system availability before modification
A_S	process system availability after modification
C	cost of process system components and equipments ($)
C_m	cost of modification ($)
H	system operating hours in a year
i	interest rate
k	expected percentage growth of operating and maintenance cost per year
m	mass flow rate of steam (kg/sec)
MTBF	mean time between failure (hours)
MTTR	mean time to repair (hours)
n	life of the process system in years
O_m	yearly operation and maintenance cost of the process system after modification ($)
O_S	yearly operation and maintenance cost of the process system before modification ($)
P/A	present value given annual rate
Q_b	energy in the steam at the boiler outlet (kW)
Q_f	energy in the fuel supplied to the boiler (kW)
Q_l	energy loss in the line due to heat dissipation from the surface of the pipe, water loss, steam loss etc (kW)
Q_r	energy in the condensate recovered from the condensate return (kW)
Q_u	theoretical useful energy required to accomplish the given task (kW)
Q_w	energy in the feed water at the boiler inlet (kW)
R	hourly production rate (units/hr)
R(t)	reliability expressed as a function of time
RBD	reliability block diagram
U	unit price of the process output ($/unit)
V	process system value ($)
V_C	change in process system value ($)
Z(t)	failure rate expressed as a function of time
μ	constant mean repair rate (hr^{-1})
η_b	boiler efficiency
η_l	efficiency of the steam line
η_m	efficiency of the pumping system after modification
η_o	overall steam system efficiency
η_r	factor of unrecovered condensate
η_u	useful task efficiency
λ	constant failure rate (hr^{-1})

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